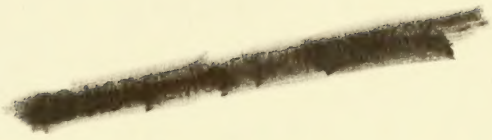

# TRANSACTIONS

OF THE

# AMERICAN SOCIETY

OF

# CIVIL ENGINEERS.

(INSTITUTED 1852.)

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(Vol. XVIII.—January, 1888.)

# DISPOSAL OF SEWAGE IN MASSACHUSETTS.

By FREDERIC P. STEARNS, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION JULY 2D, 1887.

The announcement that the disposal of sewage is one of the subjects to be discussed at the Convention this year, induces me to present to the Society a statement of the present status of this question in Massachusetts, with a brief reference to the action of the State in the matter in the past.

Massachusetts is, with one exception, the most densely populated of the States, as will be seen by the following table of the leading States in this respect:

| STATE. | Population per square mile (1880). |
|---|---|
| Rhode Island | 255 |
| Massachusetts | 222 |
| New Jersey | 152 |
| Connecticut | 129 |
| New York | 107 |
| Pennsylvania | 95 |
| Maryland | 95 |

In 1885 the population per square mile in Massachusetts was 242. It is now more densely populated than France or Germany, and is not far behind Italy or Great Britain and Ireland.

The water power of the streams has been largely developed, and the many manufactories using the water add their refuse to the streams.

For the past fifteen or twenty years it has been evident to the sanitarians who have considered the subject, that within a comparatively brief period it would be necessary to adopt some decisive measures to protect the purity of the streams.

In 1871 the State Board of Health examined one of the valleys of the State with reference to the pollution of a stream used for a water supply.

In 1872 the Legislature passed an act providing for a commission of engineers to report plans for the sewerage and water supply of the metropolitan district. They also created a commission to devise a plan for preventing the pollution of a small stream near Boston, where the co-operation of two or more cities was necessary.

In 1873 the State Board of Health, in answer to a resolve of the Legislature of 1872, submitted a lengthy report on the disposal of sewage, its utilization, the sanitary effect of draining the same into the streams and the increasing joint use of water-courses for sewers and as sources of water supply.

Since 1873 the reports of this Board have contained a large amount of valuable matter on the general subject of the disposal of sewage and much information as to the present condition of Massachusetts' rivers as regards pollution.

In 1878 a law was passed forbidding the future pollution of waters used for a domestic water supply within twenty miles above the point of taking. This law does not apply to the Merrimack and Connecticut Rivers.

In 1882, in answer to a resolve of the Legislature, the State Board of Health reported upon the pollution of the Blackstone River by the city of Worcester, recommending that it be required to purify its sewage before turning it into the stream. The same year a commission, which was appointed to consider the drainage of the Mystic and Charles River valleys, submitted their report.

In 1884 the pollution of the Blackstone River was the subject of extended hearings before a legislative committee. The same year the Massachusetts Drainage Commission was appointed "for the purpose of considering and reporting a general system of drainage for the relief of the valleys of the Mystic, Blackstone and Charles Rivers, and for the

protection of the public water supplies of the cities and towns situated within the basins of said rivers." The Commission, which was also to consider the question of the disposal of sewage, could at its discretion include other valleys in its examinations, and was given nearly two years and a liberal appropriation for its work.

The Commission appointed as its chief engineer, Mr. Eliot C. Clarke, M. Am. Soc. C. E., and his very thorough and comprehensive report was submitted to Joseph P. Davis and Rudolph Hering, Members Am. Soc. C. E., who were asked to act as consulting engineers.

Of the more important recommendations of this Commission, two were adopted by the Legislature of 1886.

By one of these the City of Worcester is required, not later than the summer of 1890, to so treat its sewage before discharging it into the Blackstone River that it shall not create a nuisance or endanger the public health.

The engineer of this city, Mr. C. A. Allen, M. Am. Soc. C. E., has recently made a report recommending that chemical precipitation be adopted.

By the adoption of the second recommendation of the Commission the State has now a general law relating to the supervision of water supply and sewerage, its execution being intrusted to the State Board of Health.

The foregoing indicates the growth of the sewerage question in Massachusetts.

The general law referred to is the first of its kind in the country, so far as the writer is informed, and some space will be devoted to a statement of its provisions and of its execution up to the present time.

The law is given in full as an appendix.

The duties of the Board of Health under this law may be stated concisely as follows:

*First.*—To have the general care and oversight of inland waters.

*Second.*—To recommend legislation and suitable plans for systems of main sewers.

*Third.*—To cause examinations of the waters of ponds and streams to be made.

*Fourth.*—To recommend measures to prevent the pollution of waters.

*Fifth.*—To conduct experiments on the purification of drainage.

*Sixth.*—To conduct experiments on the disposal of manufacturing refuse.

*Seventh.*—To consult with and advise the authorities of cities and towns and others as to the most appropriate source of water supply and

the best practical method of assuring the purity thereof or of disposing of their sewage, having regard to the present and prospective needs of cities, towns, etc., affected thereby.

*Eighth.*—To consult with and advise manufacturers with reference to the disposal of manufacturing refuse.

*Ninth.*—To bring to the notice of the Attorney-General all omissions to comply with existing laws.

The law further provides that authorities of cities and towns, and all others intending to introduce systems of water supply or sewerage, shall submit to the Board outlines of their proposed plans or schemes in relation to these subjects; and that manufacturers intending to engage in any business, drainage or refuse from which may tend to cause the pollution of any inland waters, shall also give notice to the Board of their intentions in the premises.

The Board consists of seven members, of whom one is a prominent civil engineer, one a physician who for many years has made water supply and sewerage questions a special study, one a lawyer and the others physicians and business men.

The engineering staff of the Board at the present time consists of Joseph P. Davis, M. Am. Soc. C. E., Consulting Engineer; the writer, Chief Engineer, and one permanent and two temporary assistants.

The work of the Board during the nine months in which the law has been in practical operation has consisted chiefly in advising cities, towns and public institutions about proposed plans of water supply and sewerage, though they have begun upon monthly chemical examinations of waters from all public water supplies and the more important rivers; these examinations to be supplemented by biological and microscopic work by experts. It is hoped that much information may be gained by these systematic researches. Plans are under consideration for some accurate experiments on the disposal of sewage at one of the public institutions.

The proposed systems of sewerage submitted by cities and towns have included combined and separate systems, and the disposal of sewage by purification upon land and by direct discharge into water-courses; all of which have been approved where, after thorough examination, they appeared to be best suited to the circumstances of the cases, and nearly all have been disapproved under other circumstances.

The experience thus far gained has helped to emphasize the need, well known before, of some restriction upon the discharge of polluting matters into the ponds and streams of the State, as well as to show for-

cibly the difficulty of making this restriction by any laws applied without discrimination to all cases. The plan adopted of making this restriction through the agency of a Board having power to examine each case with the aid of experts and decide each upon its merits seems to be the best that could be adopted and one to be recommended to other States.

In Massachusetts the Board is given advisory and not mandatory powers ; whether this will be sufficient or not is a question. It has proved sufficient for the Massachusetts Railroad Commission for many years and for the Board during the brief time that the law under consideration has been in operation and I think it will continue to be so.

Up to the present time only two towns in Massachusetts, Lenox and Medfield, have built works for purification, and these, with the public institutions, notably the reformatories at Concord and Sherborn and the Insane Hospital at Worcester, furnish the only important examples of sewage purification in the State.

During the next few years several other examples will probably be furnished, since Worcester is required by law to purify its sewage within three years, and the city of Brockton and the towns of Milford, Framingham and Marlborough are proposing to dispose of their sewage upon land. Lenox is proposing to build additional works, and many other cities and towns desirous of providing sewerage facilities, realize that they must adopt some purification processes.

# APPENDIX.

## COMMONWEALTH OF MASSACHUSETTS.

[Chap. 274.]

An Act to protect the purity of inland waters.

*Be it enacted, etc., as follows:*

Section 1. The State Board of Health shall have the general oversight and care of all inland waters and shall be furnished with maps, plans and documents suitable for this purpose, and records of all its doings in relation thereto shall be kept. It may employ such engineers and clerks and other assistants as it may deem necessary; provided, that no contracts or other acts which involve the payment of money from the treasury of the Commonwealth shall be made or done without an appropriation expressly made therefor by the general court. It shall annually on or before the tenth day of January report to the general court its doings in the preceding year, and at the same time submit estimates of the sums required to meet the expenses of said board in relation to the care and oversight of inland waters for the ensuing year; and it shall also recommend legislation and suitable plans for such systems of main sewers as it may deem necessary for the preservation of the public health and for the purification and prevention of pollution of the ponds, streams and inland waters of the Commonwealth.

Sec. 2. Said board shall from time to time as it may deem expedient, cause examinations of the said waters to be made for the purpose of ascertaining whether the same are adapted for use as sources of domestic water supplies or are in a condition likely to impair the interests of the public or persons lawfully using the same, or imperil the public health. It shall recommend measures for prevention of the pollution of such waters and for removal of substances and causes of every kind which may be liable to cause pollution thereof, in order to protect and develop the rights and property of the Commonwealth therein and to protect the public health. It shall have authority to conduct experiments to determine the best practical methods of purification of drainage or disposal of refuse arising from manufacturing and other industrial establishments. For the purposes aforesaid it may employ such expert assistance as may be necessary.

Sec. 3. It shall from time to time consult with and advise the authorities of cities and towns, or with corporations, firms or individuals either already having or intending to introduce systems of water supply or sewerage, as to the most appropriate source of supply, the best practical method of assuring the purity thereof or of disposing of their sewage, having regard to the present and prospective needs and interests of other cities, towns, corporations, firms or individuals which may be affected thereby. It shall also from time to time consult with and advise persons or corporations engaged or intending to engage in any manufacturing or other business, drainage or refuse from which may tend to cause the pollution of any inland water, as to the best practical method of preventing such pollution by the interception, disposal or purification of such drainage or refuse; provided, that no person shall be compelled to bear the expense of such consultation or advice, or of experiments made for the purposes of this act. All such authorities, corporations, firms and individuals are hereby required to give notice to said board

of their intentions in the premises, and to submit for its advice outlines of their proposed plans or schemes in relation to water supply and disposal of drainage or refuse. Said board shall bring to the notice of the attorney-general all instances which may come to its knowledge of omission to comply with existing laws respecting the pollution of water supplies and inland waters and shall annually report to the legislature any specific cases not covered by the provisions of existing laws, which in its opinion call for further legislation. [Approved June 9, 1886.]

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(Vol. XVIII.—January, 1888.)

# SEWAGE DISPOSAL.

By CHARLES A. ALLEN, M. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION—JULY 2D, 1887.

In the fall of 1883 I received instructions from the City Council of the City of Worcester, Mass., to visit Europe, for the purpose of examining the various methods of sewage disposal in use there, the information so obtained to be used in suits brought against the city, for polluting the Blackstone River, and also to be used in determining the best method of disposing of the sewage of the city, in case it should be found necessary in the course of time, so to do. In September, 1886, I received instructions to prepare a report upon the subject, and to recommend what, in my opinion, would be the most practicable system of disposal for the city to adopt. The report has been made and published, and as it presents my views upon the subject, I shall take the liberty of quoting largely therefrom, taking care to use only such portions of the report as bear upon the general subject, and not upon local conditions.

As the history of sewage purification in England is exceedingly interesting, and dates back nearly half a century, a brief review will perhaps be instructive.

Early in the present century it became apparent that, owing to the great pollution of the rivers and streams flowing through the densely

populated districts, some method of purification must be adopted; coupled with this, was the belief that large sums of money could be made out of the sewage, by devising some method of converting it into a fertilizer.

A large amount of capital was invested in works for this purpose, nearly all of which was lost.

Commissions appointed by towns, cities and the general government, investigated the subject, and made elaborate reports and recommendations. A bare quotation of the titles of these would fill quite a volume and is out of the question here.

By most of the methods tried, it was found possible to extract the solid matters contained in the sewage, but when this was accomplished, it was found that the extract, in many instances, was valueless, and that the effluent obtained, in every case, was anything but pure.

I will give a few examples of the early efforts made, as they bear upon the subjects of sedimentation and mechanical filtration, which have been suggested as possible means of purifying sewage.

At Aldershot and Rugby, the sewage was strained through planks perforated with holes ¾ of an inch in diameter, but the purifying effect was slight, for the amount of suspended matter was only reduced from 43.77 grains per gallon to 35.01 at Aldershot, with about the same result at Rugby, while the organic matter was 14.02 grains per gallon, before, and 8.77 grains per gallon after, treatment.

Even with a more elaborate system of filtration, as was practiced at Merthyr-Tydfil, where the sewage passed through a filter of coarse iron slag, about three feet thick, and then through another filter of coarse vegetable charcoal, the suspended matters were reduced from 169.81 grains to 32.31 grains per gallon; but the soluble matters were not affected.

A Mr. Strong, of Glasgow, designed an apparatus for filtering sewage, the filtering medium being coal ashes.

The filtration was upward, so that the solid matter was retained in the lower part of the filter. This apparatus was tried at a public institution in Glasgow, having about two hundred inmates; the effluent was very free from suspended matters, but the soluble portion of the sewage escaped untouched.

At Birmingham sand filters were at one time used with about the same success, while at Chelmsford and Belston, clinkers and ashes were

employed. It was found that if the filtering material was fine in its texture, it very soon clogged; and if coarse, it failed to remove a large amount of matter carried in suspension.

Other examples of mechanical filtration might be quoted, if necessary, the result obtained in every instance being about the same.

Birmingham originally tried subsiding tanks. They were arranged so that the sewage was discharged into a tank about ninety feet long and fifty feet wide; from thence it flowed over a weir guarded by floating boards placed for the purpose of intercepting floating matters, into a tank of similar dimensions, and then over a like weir into a third tank (30 feet wide and 150 feet long), from this into another of about three times the capacity of the last, and then over a weir into the effluent channel which conveyed it to the River Rea. In this manner a large portion of the heavier matters in the sewage was deposited in the tanks, for it took about two hours for the sewage to pass through the entire series; but still the effluent water was very offensive and was the cause of serious nuisance to those who had an interest in the river below the works, or as the report of Dr. Lethby states: "The whole of the works are in a very unsatisfactory condition, and are a serious nuisance to the neighborhood."

This is only one of many examples that might be cited.

The combined system of sedimentation and filtration was scarcely more successful. At Coventry, for instance, the sewage was first allowed to stand in settling tanks; it was then filtered through a lateral filter of coarse gravel (running the whole length of the tank), 150 feet long, 49 feet wide, 9 feet deep. From this tank the sewage ran into another of the same dimensions, from which it passed through a filter of the same size as the first, of finer gravel and from that into the stream. The sludge was mixed with the ashes and sweepings of the town and commanded a good price as a fertilizer, the works being nearly self-supporting, but the purification was so imperfect that they were abandoned.

At Uxbridge the sewage after standing in a subsiding tank was filtered through charcoal. This was also found to be so imperfect that it was soon abandoned.

The above facts were obtained from reports.

The history of sewage treatment in England is full of just such failures as are quoted above; for, while some of the methods of artificial filtration and sedimentation were nearly self-supporting, none of them

paid, and all of them produced so poor an effluent that they were soon abandoned.

As it became evident that simple subsidence and filtration could not be made to pay, more attention was given to irrigation and chemical precipitation. Where irrigation was adopted it was hoped that by applying the sewage to the land and raising crops a fair profit could be made and a pure effluent obtained at the same time. And from that time until the present day this effort has been earnestly made. The result is, however, that while in the majority of cases under proper and careful management, and when the climatic conditions are favorable, a good effluent is obtained, in no case, so far as I am able to learn, has a profit ever been made, for the sewage comes night and day, in season and out of season, during rainy weather and dry weather, and demands constant attention. The effect upon vegetation can be imagined, for often the land is soaked with about twice the amount of water that comes in the rainfall besides the rainfall itself. There are exceptions to this, of course, but the above statement is true in most cases.

Most of the vegetables grown are very coarse and are used principally for feeding cattle. Experience has shown that to obtain anything like a good effluent it is necessary to provide one acre of land for each one hundred inhabitants in the district drained, that the land so used shall have a subsoil of gravel or sand, that in many cases it shall be properly underdrained, the drains being not less than five feet below the surface of the ground, and that in times of heavy storms the sewage shall be filtered through beds especially prepared for that purpose.

In many cases, however, this latter method is not employed, the sewage being simply turned into the streams during storms.

Meanwhile the purification of sewage by chemical precipitation received the earnest attention of a large number of scientific men, the hope being entertained that by the introduction of different chemicals into it, a fair profit from the sale of the sludge as a fertilizer would be realized, and at the same time a good effluent obtained.

Companies were formed, and different processes patented, nearly all of these producing a fair effluent, but they were so expensive that most of the companies lost money, and but few of them survived. It was found that, while the introduction of chemicals, to a certain extent, made the sludge more valuable as a fertilizer, the income derived from the improvement was not great enough to anywhere near pay the oper-

ating expenses. In fact, the disposal of the sludge was the great drawback to this method of sewage treatment; at the present time there is very little sale for it, and in a great many places the farmers will not draw it away if given them.

As before stated, most of the processes at first tried were abandoned, as it was found that the best results were obtained by either one of the three following methods:

"The Lime Process," which is the most extensively used, the "Coventry Process," and the "A B C Process." This latter method is very expensive, and is not in general use.

While the disposal of the sludge was, and in some cases is, a great drawback to this method of treatment, still there is sufficient merit in the system to induce about fifty cities and towns in England, to adopt it in some form.

The old method of disposing of the sludge is open to quite serious objections, not only from an economic, but from a sanitary point of view. The sludge, which in all cases contains about 90 per cent. of water, is spread upon land and allowed to dry sufficiently to handle readily, or else is dried in vats especially prepared for the purpose. In a short time it becomes more or less offensive, especially in warm weather; and if in close proximity to buildings, is a nuisance. By the adoption of sludge presses, however, this difficulty is entirely removed, for a large percentage of the moisture is extracted, leaving the compressed cake in a condition to be readily handled.

It is also very much more valuable as a fertilizer, as the cakes can be taken and used when fresh, while by the old process of sun-drying, a large percentage of the manurial qualities of the sludge is lost by the evaporation and exposure to the air.

At the present time, chemical precipitation is recognized in England, as being one of the best methods for treating large quantities of sewage.

Dr. Frankland, in 1870, suggested downward intermittent filtration, as a means of purifying sewage; and this method of purification was soon adopted by Mr. Bailey Denton in his practice.

It differs from broad irrigation, in that, instead of spreading sewage over a large surface of ground, and having in view the raising of crops, as one of the principal objects to be attained, a small area of porous land is selected and thoroughly underdrained, the tract being

divided so that while the sewage is applied to one section, the other has a chance to rest, the object of intermittence being to thoroughly aerate the bed not in use, so that when the sewage is again applied, the soil will be in a fit condition to purify it.

This method has been adopted in several instances, where the amount of sewage to be treated is small, and in many cases, in connection with irrigation and precipitation. It is claimed by the advocates of this method that to properly purify the sewage the land must be porous, and must be thoroughly underdrained, the drains being at least five feet below the surface of the ground.

It is claimed that the sewage from not more than one thousand people can be applied to each acre of prepared land, but this is not advisable unless the solids are to some extent removed. And crude sewage from not more than five hundred persons can be applied to each acre, with good prospects of success.

It will be seen that there are three distinct methods now employed abroad for treating sewage, they being subject to such modifications as are necessary in designing works for different localities.

Irrigation and chemical precipitation are the most extensively employed, downward intermittent filtration being principally used as an auxiliary to one of the other methods, although, as stated, there are places where a comparatively small quantity of sewage is to be treated, where this method alone is employed.

Under favorable conditions, and when carefully and judiciously managed, the effluent obtained by either process is fairly satisfactorily, sufficiently so in most cases, to warrant its discharge into a stream not used for water-supply purposes.

The expense of treatment being considerable, however, the tendency is to use the works so as to bring in the greatest income. This, judging from the results obtained abroad, should never be allowed, for it has been found that as the income increases, the purity of the effluent is very likely to be affected, owing to the fact that it is very rarely the case, that all the sewage can be applied to the land without injury to plant life. This is the reason why, on most sewage farms, the sewage is turned into the nearest stream during stormy weather, or when the ground becomes surcharged with water from any cause.

Now the conditions, climatic and other, that exist in central Massachusetts, are not as favorable to the proper treatment of sewage by

irrigation or by filtration, as in England and France, or even in Germany, at Berlin and Dantzic.

Although the claim has been made in reports upon the subject that there is no material difference, I think, however, that there is a reasonable doubt about this. The following statements of the difference in temperatures, will show a decided difference in climatic conditions during the winter months. The temperatures at Dantzic were obtained from Mr. Aird, the manager of the farm at that place, and are official; while the temperatures for Massachusetts were taken from the records at Worcester.

The following table gives the differences in temperature for five winters, beginning with December 1st, 1877, and ending March 31st, 1883:

| Dantzic. | Average Monthly Temperature. | Worcester. | Average Monthly Temperature. |
|---|---|---|---|
| December, 1878, | 34 degrees Fahr. | December, 1878, | 25 degrees Fahr. |
| January, 1879, | 28 " | January, 1879, | 20 " |
| February, " | 32 " | February, " | 20 " |
| March, " | 33 " | March, " | 30 " |
| Average by mos. | 31.75 " | Average by mos. | 23.75 " |
| December, 1879, | 27 degrees Fahr. | December, 1879, | 28 degrees Fahr. |
| January, 1880, | 29 " | January, 1880, | 30 " |
| February, " | 31 " | February, " | 27 " |
| March, " | 36 " | March, " | 29 " |
| Average by mos. | 30.75 " | Average by mos. | 28.5 " |
| December, 1880, | 34 degrees Fahr. | December, 1880, | 20 degrees Fahr. |
| January, 1881, | 23 " | January, 1881, | 16 " |
| February, " | 28 " | February, " | 23 " |
| March, " | 34 " | March, " | 32 " |
| Average by mos. | 29.5 " | Average by mos. | 22.75 " |
| December, 1881, | 34 degrees Fahr. | December, 1881, | 33 degrees Fahr. |
| January, 1882, | 37 " | January, 1882, | 21 " |
| February, " | 38 " | February, " | 25 " |
| March, " | 44 " | March, " | 32 " |
| Average by mos. | 38.25 " | Average by mos. | 27.75 " |
| December, 1882, | 26 degrees Fahr. | December, 1882, | 23 degrees Fahr. |
| January, 1883, | 27 " | January, 1883, | 18 " |
| February, " | 30 " | February, " | 22 " |
| March, " | 26 " | March, " | 23 " |
| Average by mos. | 29.75 " | Average by mos. | 21.5 " |

It will be noticed that with the exception of the winter of 1879–80, the mercury ranged much lower here (Central Massachusetts) than at Dantzic, a difference of from 7 degrees to 8 degrees Fahr. for the entire season, being the general amount. This, of course, makes a great difference in frost penetration, and adds to the liability of the ground remaining frozen.

An examination of the accompanying tables of daily temperatures shows that in the five years covered by the tables given above, at Dantzic there were only three days during that period that the thermometer registered below zero, the extreme being 4 degrees below, while at Worcester, during the same period, there were forty days below zero, with an extreme of 18 degrees below.

At Dantzic, there were thirty-eight days in which the thermometer registered from zero to 10 degrees above, while at Worcester, there were 124 days.

At Dantzic, there were 73 days in which the temperature was between 10 and 20 degrees above zero, while at Worcester there were 164 days.

While there were 346 days at Dantzic in which the thermometer registered between 20 and 32 degrees above, at Worcester there were 221 days.

The total number of days covered by the observations in the five years was 606. Of this number Dantzic had 460 below the freezing point, or about 75.9 per cent., while Worcester had 542 days or 89.4 per cent.

While Dantzic had only 114 days below 20 degrees, or 18.8 per cent. Worcester had 328, or 54.1 per cent.

At Berlin the sewage is stored in large reservoirs during the severest portion of the winter, no attempt being made to purify by irrigation, while at Dantzic it is constantly applied to the land without regard to the weather, the manager stating that while the action of the frost interfered somewhat with the operation of the works, still the periods of extreme cold were of so short duration that no serious difficulty was experienced.

A glance at the table of temperatures will illustrate this fact—for instance, from the 25th to the 28th inclusive of January, 1881, was the coldest weather indicated for any four consecutive days in the five years. For the following twenty days the temperature averaged 33 degrees, one

# TABLE No. 1.

## Temperature in Fahrenheit at Dantzic.

| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | | 11 | | 12 | | 13 | | 14 | | 15 | | 16 | | 17 | | 18 | | 19 | | 20 | | 21 | | 22 | | 23 | | 24 | | 25 | | 26 | | 27 | | 28 | | 29 | | 30 | | 31 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. |
| 1878-79. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec. ... | 39 | 37 | 43 | 37 | 46 | 43 | 43 | 39 | 43 | 41 | 41 | 37 | 37 | 32 | 34 | 30 | 37 | 32 | 37 | 34 | 37 | 34 | 34 | 34 | 37 | 32 | 32 | 23 | 28 | 23 | 28 | 25 | 39 | 25 | 30 | 25 | 30 | 23 | 37 | 30 | 32 | 28 | 32 | 30 | 32 | 28 | 34 | 25 | 32 | 25 | 30 | 23 | 37 | 30 | 39 | 37 | 41 | 32 | 41 | 32 | 46 | 41 |
| Jan .... | 48 | 32 | 37 | 32 | 37 | 30 | 37 | 30 | 32 | 30 | 32 | 25 | 30 | 19 | 32 | 25 | 28 | 14 | 25 | 14 | 28 | 21 | 30 | 28 | 32 | 30 | 32 | 28 | 32 | 28 | 30 | 28 | 30 | 28 | 32 | 28 | 28 | 28 | 34 | 28 | 28 | 23 | 23 | 19 | 32 | 19 | 24 | 32 | 37 | 32 | 32 | 28 | 32 | 28 | 37 | 32 | 34 | 25 | 25 | 5 | 14 | 7 |
| Feb .... | 21 | 10 | 28 | 5 | 23 | 5 | 28 | 14 | 28 | 14 | 37 | 28 | 41 | 37 | 41 | 37 | 43 | 41 | 46 | 39 | 52 | 34 | 46 | 34 | 37 | 32 | 34 | 25 | 34 | 28 | 32 | 28 | 30 | 28 | 30 | 28 | 37 | 30 | 37 | 28 | 34 | 21 | 39 | 25 | 39 | 32 | 39 | 32 | 41 | 34 | 37 | 24 | 37 | 34 | 37 | 34 | 37 | 34 | 57 | 32 | .. | .. | .. | .. | .. | .. | .. | .. |
| March . | 37 | 30 | 37 | 28 | 37 | 32 | 39 | 32 | 39 | 34 | 43 | 37 | 43 | 37 | 43 | 39 | 48 | 39 | 46 | 39 | 43 | 23 | 37 | 28 | 34 | 23 | 32 | 25 | 34 | 25 | 34 | 28 | 34 | 25 | 37 | 28 | 41 | 28 | 39 | 28 | 32 | 23 | 32 | 28 | 30 | 21 | 32 | 28 | 34 | 23 | 34 | 23 | 34 | 28 | 34 | 30 | 37 | 32 | 41 | 34 | 50 | 28 |
| 1879-80. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec .... | 23 | 5 | 16 | 3 | 21 | 14 | 21 | 5 | 19 | 10 | 25 | 19 | 19 | 1 | 10 | −2 | 23 | 5 | 25 | 14 | 34 | 25 | 34 | 28 | 37 | 30 | 34 | 30 | 41 | 34 | 39 | 37 | 39 | 34 | 37 | 32 | 37 | 32 | 37 | 19 | 32 | 19 | 43 | 37 | 41 | 34 | 39 | 34 | 39 | 30 | 32 | 37 | 19 | 32 | 19 | 43 | 37 | 41 | 34 | 39 | 34 |
| Jan .... | 59 | 30 | 43 | 32 | 41 | 39 | 41 | 37 | 41 | 34 | 39 | 34 | 39 | 34 | 37 | 32 | 37 | 34 | 34 | 28 | 37 | 34 | 34 | 34 | 37 | 34 | 37 | 30 | 30 | 21 | 25 | 23 | 28 | 14 | 25 | 21 | 23 | 14 | 28 | 16 | 32 | 23 | 32 | 16 | 32 | 16 | 37 | 25 | 34 | 23 | 32 | 7 | 30 | 7 | 34 | 19 | 30 | 14 | 32 | 7 | 25 | 5 |
| Feb .... | 32 | 12 | 34 | 14 | 41 | 28 | 41 | 30 | 37 | 25 | 34 | 30 | 37 | 28 | 37 | 28 | 37 | 25 | 37 | 28 | 37 | 28 | 37 | 28 | 34 | 28 | 34 | 32 | 34 | 28 | 30 | 25 | 28 | 7 | 16 | 10 | 37 | 10 | 46 | 37 | 46 | 37 | 57 | 37 | 30 | 37 | 25 | 32 | 25 | 34 | 25 | 39 | 32 | 39 | 30 | 39 | 32 | 43 | 32 | .. | .. | .. | .. | .. |
| March . | 50 | 37 | 43 | 39 | 48 | 45 | 46 | 39 | 43 | 32 | 43 | 34 | 48 | 32 | 34 | 28 | 46 | 32 | 55 | 37 | 39 | 32 | 32 | 25 | 34 | 28 | 39 | 28 | 34 | 28 | 41 | 32 | 34 | 23 | 30 | 21 | 39 | 32 | 37 | 30 | 39 | 25 | 39 | 25 | 39 | 30 | 39 | 32 | 43 | 30 | 43 | 28 | 50 | 30 | 43 | 34 | 48 | 34 | 37 | 32 | 46 | 34 |
| 1880-81. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec .... | 43 | 41 | 43 | 32 | 34 | 30 | 32 | 25 | 37 | 28 | 28 | 25 | 41 | 28 | 43 | 39 | 46 | 32 | 39 | 32 | 41 | 39 | 43 | 37 | 37 | 34 | 37 | 30 | 30 | 25 | 32 | 25 | 32 | 14 | 34 | 10 | 39 | 34 | 37 | 24 | 41 | 32 | 37 | 30 | 39 | 25 | 41 | 34 | 43 | 34 | 39 | 37 | 37 | 32 | 37 | 32 | 41 | 34 | 41 | 39 | 41 | 32 |
| Jan .... | 37 | 30 | 39 | 32 | 43 | 39 | 39 | 37 | 37 | 30 | 37 | 32 | 37 | 32 | 34 | 28 | 32 | 28 | 32 | 21 | 23 | 16 | 23 | 16 | 19 | 10 | 23 | 10 | 19 | 12 | 21 | 16 | 21 | 3 | 12 | 10 | 19 | 10 | 25 | 14 | 21 | 12 | 28 | 19 | 30 | 19 | 23 | 1 | 14 | -4 | 10 | 4 | 30 | 7 | 34 | 30 | 37 | 34 | 37 | 32 |
| Feb .... | 41 | 30 | 37 | 32 | 34 | 32 | 34 | 32 | 37 | 30 | 37 | 30 | 39 | 21 | 37 | 25 | 41 | 34 | 39 | 32 | 41 | 28 | 30 | 25 | 34 | 21 | 32 | 30 | 34 | 30 | 37 | 32 | 37 | 32 | 32 | 16 | 23 | 16 | 25 | 16 | 30 | 21 | 32 | 16 | 32 | 19 | 39 | 19 | 39 | 19 | 37 | 30 | 32 | 16 | 28 | 16 | .. | .. | .. | .. | .. | .. |
| March . | 43 | 28 | 30 | 25 | 32 | 25 | 30 | 23 | 28 | 21 | 28 | 14 | 34 | 19 | 46 | 41 | 46 | 34 | 43 | 32 | 37 | 32 | 43 | 34 | 34 | 28 | 32 | 25 | 37 | 25 | 43 | 30 | 50 | 34 | 48 | 34 | 46 | 34 | 41 | 30 | 41 | 21 | 34 | 23 | 39 | 25 | 41 | 30 | 41 | 37 | 43 | 30 | 43 | 32 | 50 | 30 | 46 | 32 | 41 | 30 | 46 | 32 |
| 1881-82. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec .... | 48 | 37 | 39 | 37 | 37 | 28 | 32 | 30 | 34 | 30 | 34 | 32 | 34 | 32 | 32 | 32 | 39 | 32 | 34 | 28 | 32 | 30 | 37 | 32 | 32 | 30 | 34 | 30 | 30 | 21 | 46 | 21 | 32 | 23 | 39 | 32 | 41 | 34 | 37 | 32 | 37 | 32 | 37 | 32 | 37 | 28 | 32 | 28 | 32 | 28 | 39 | 32 | 43 | 41 | 43 | 34 | 41 | 37 | 43 | 34 | 37 | 34 |
| Jan .... | 39 | 30 | 39 | 30 | 46 | 39 | 43 | 39 | 41 | 39 | 46 | 39 | 46 | 41 | 41 | 39 | 41 | 37 | 43 | 41 | 43 | 37 | 39 | 34 | 37 | 28 | 34 | 23 | 34 | 25 | 39 | 28 | 37 | 2 | 39 | 37 | 41 | 39 | 43 | 39 | 41 | 41 | 41 | 37 | 37 | 37 | 43 | 37 | 43 | 39 | 43 | 32 | 37 | 32 | 39 | 34 | 43 | 32 | 37 | 30 | 34 | 32 |
| Feb .... | 39 | 32 | 39 | 28 | 34 | 30 | 39 | 34 | 39 | 37 | 41 | 32 | 32 | 30 | 30 | 30 | 43 | 30 | 39 | 34 | 37 | 34 | 34 | 25 | 41 | 30 | 50 | 39 | 46 | 32 | 46 | 32 | 41 | 32 | 43 | 34 | 43 | 32 | 41 | 32 | 43 | 25 | 43 | 25 | 48 | 34 | 48 | 41 | 43 | 39 | 57 | 43 | 57 | 48 | 52 | 32 | .. | .. | .. | .. | .. | .. |
| March.. | 37 | 32 | 52 | 37 | 52 | 39 | 41 | 39 | 46 | 41 | 50 | 39 | 37 | 34 | 50 | 39 | 50 | 41 | 52 | 46 | 52 | 39 | 46 | 39 | 50 | 43 | 52 | 41 | 57 | 59 | 55 | 39 | 50 | 37 | 41 | 30 | 55 | 32 | 66 | 32 | 68 | 41 | 50 | 37 | 46 | 34 | 46 | 39 | 48 | 41 | 46 | 34 | 50 | 41 | 48 | 43 | 48 | 41 | 52 | 46 | 59 | 43 |
| 1882-83. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec .... | 21 | 16 | 19 | 14 | 14 | 10 | 16 | 10 | 25 | 16 | 30 | 25 | 32 | 28 | 34 | 28 | 34 | 32 | 30 | 23 | 34 | 30 | 34 | 30 | 32 | 30 | 34 | 32 | 32 | 30 | 34 | 30 | 30 | 21 | 21 | 14 | 21 | 14 | .. | .. | 25 | 19 | 28 | 25 | 28 | 25 | 30 | 25 | 32 | 21 | 32 | 23 | 30 | 19 | 43 | 21 | 41 | 25 | 43 | 30 | 30 | 25 |
| Jan .... | 30 | 21 | 39 | 32 | 39 | 32 | 32 | 28 | 43 | 12 | 23 | 16 | 28 | 19 | 32 | 28 | 32 | 32 | 32 | 25 | 28 | 14 | 25 | 12 | 28 | 14 | 19 | 12 | 19 | 12 | 21 | 12 | 28 | 21 | 32 | 23 | 34 | 23 | 34 | 32 | 34 | 30 | 32 | 28 | 28 | 16 | 16 | 19 | 21 | 19 | 28 | 21 | 34 | 25 | 37 | 30 | 37 | 30 | 43 | 28 | 37 | 28 |
| Feb .... | 34 | 28 | 37 | 30 | 43 | 30 | 39 | 32 | 34 | 30 | 30 | 25 | 28 | 25 | 25 | 23 | 23 | 21 | 30 | 21 | 34 | 23 | 43 | 28 | 34 | 23 | 34 | 28 | 30 | 19 | 25 | 14 | 28 | 14 | 32 | 16 | 28 | 14 | 28 | 12 | 39 | 23 | 46 | 34 | 39 | 32 | 39 | 30 | 39 | 24 | 34 | 28 | 37 | 30 | 41 | 32 | .. | .. | .. | .. | .. | .. |
| March.. | 34 | 30 | 32 | 25 | 39 | 25 | 41 | 28 | 37 | 32 | 37 | 25 | 28 | 21 | 28 | 19 | 37 | 12 | 25 | 3 | 25 | 5 | 30 | 23 | 30 | 16 | 30 | 10 | 25 | 7 | 32 | 10 | 30 | 10 | 30 | 10 | 32 | 23 | 30 | 23 | 25 | 7 | 19 | 3 | 28 | 14 | 32 | 19 | 32 | 23 | 39 | 25 | 41 | 28 | 39 | 30 | 37 | 30 | 39 | 30 | 39 | 28 |

# TABLE No. 2.

## Temperature in Fahrenheit at Worcester.

| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | | 11 | | 12 | | 13 | | 14 | | 15 | | 16 | | 17 | | 18 | | 19 | | 20 | | 21 | | 22 | | 23 | | 24 | | 25 | | 26 | | 27 | | 28 | | 29 | | 30 | | 31 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. | Max. | Min. |
| 1878-79. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec..... | 36 | 20 | 52 | 34 | 41 | 38 | 35 | 33 | 32 | 27 | 28 | 23 | 24 | 14 | 26 | 18 | 27 | 24 | 54 | 33 | 38 | 34 | 34 | 30 | 32 | 28 | 30 | 21 | 33 | 30 | 26 | 20 | 24 | 11 | 28 | 20 | 26 | 20 | 28 | 17 | 25 | 18 | 34 | 30 | 24 | 16 | 15 | 12 | 21 | 11 | 22 | 14 | 29 | 20 | 23 | 20 | 22 | 11 | 24 | 18 | 24 | 10 |
| Jan..... | 30 | 16 | 29 | 20 | 10 | -1 | 20 | 12 | 23 | 16 | 20 | 12 | 20 | 6 | 32 | 22 | 33 | 28 | 27 | 11 | 22 | 10 | 25 | 8 | 32 | 22 | 34 | 20 | 8 | 3 | 12 | 2 | 28 | 5 | 32 | 10 | 25 | 10 | 19 | 8 | 12 | 3 | 32 | 26 | 34 | 26 | 30 | 18 | 38 | 26 | 8 | 2 | 31 | 6 | 44 | 36 | 30 | 20 | 24 | 10 | 30 | 16 |
| Feb..... | 21 | 16 | 20 | 8 | 29 | 22 | 29 | 26 | 32 | 18 | 30 | 23 | 28 | 10 | 24 | 14 | 28 | 16 | 14 | 2 | 42 | 30 | 42 | 30 | 24 | 20 | 14 | 6 | 12 | 0 | 26 | 6 | 35 | 20 | 22 | 18 | 18 | 5 | 22 | 14 | 13 | 10 | 19 | 2 | 35 | 16 | 14 | 10 | 25 | 6 | 44 | 20 | 18 | 12 | 11 | 0 | .. | .. | .. | .. | .. | .. | .. | .. |
| March.. | 30 | 12 | 33 | 24 | 32 | 22 | 38 | 23 | 40 | 26 | 26 | 8 | 30 | 25 | 31 | 6 | 34 | 26 | 44 | 32 | 50 | 38 | 35 | 27 | 39 | 32 | 42 | 30 | 32 | 27 | 32 | 17 | 32 | 22 | 25 | 17 | 32 | 10 | 34 | 20 | 34 | 28 | 38 | 17 | 33 | 30 | 38 | 20 | 36 | 34 | 42 | 26 | 32 | 32 | 34 | 30 | 49 | 30 | 48 | 32 | 31 | 23 |
| 1879-80. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec..... | 40 | 16 | 46 | 28 | 52 | 36 | 48 | 36 | 39 | 26 | 40 | 32 | 48 | 42 | 42 | 40 | 34 | 28 | 41 | 28 | 56 | 38 | 32 | 24 | 30 | 18 | 32 | 26 | 36 | 30 | 31 | 26 | 34 | 28 | 14 | 1 | 30 | 22 | 32 | 22 | 2 | 0 | 14 | 0 | 28 | 20 | 34 | 30 | 34 | 22 | 10 | 5 | 46 | 8 | 34 | 22 | 40 | 30 | 40 | 24 | 8 | 4 |
| Jan..... | 30 | 10 | 40 | 34 | 28 | 22 | 44 | 36 | 38 | 28 | 32 | 22 | 36 | 28 | 36 | 20 | 32 | 30 | 40 | 32 | 38 | 32 | 46 | 34 | 22 | 12 | 22 | 4 | 38 | 21 | 37 | 26 | 44 | 30 | 36 | 30 | 38 | 32 | 32 | 30 | 24 | 18 | 26 | 6 | 38 | 36 | 32 | 18 | 10 | 16 | 42 | 26 | 38 | 32 | 48 | 36 | 26 | 12 | 34 | 10 | 40 | 28 |
| Feb..... | 28 | 12 | 8 | -10 | 28 | 8 | 22 | 14 | 22 | 8 | 22 | 18 | 30 | 8 | 22 | 3 | 28 | 4 | 22 | 12 | 31 | 8 | 43 | 36 | 44 | 42 | 42 | 30 | 32 | 26 | 32 | 23 | 44 | 30 | 55 | 40 | 28 | 18 | 20 | 10 | 32 | 20 | 32 | 20 | 34 | 30 | 24 | 10 | 40 | 24 | 44 | 36 | 48 | 34 | 52 | 30 | 54 | 46 | .. | .. | .. | .. | .. |
| March.. | 34 | 30 | 32 | 14 | 46 | 24 | 52 | 44 | 54 | 42 | 36 | 32 | 38 | 24 | 32 | 22 | 20 | 10 | 34 | 22 | 20 | 14 | 28 | 20 | 30 | 13 | 32 | 22 | 40 | 22 | 32 | 26 | 32 | 30 | 30 | 14 | 32 | 26 | 30 | 24 | 38 | 28 | 44 | 24 | 40 | 30 | 32 | 20 | 24 | 12 | 34 | 18 | 33 | 24 | 30 | 30 | 38 | 24 | 35 | 28 | 41 | 24 |
| 1880-81. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec..... | 28 | 20 | 25 | 16 | 22 | 14 | 28 | 16 | 31 | 22 | 34 | 30 | 26 | 18 | 16 | 4 | 18 | 10 | 12 | 8 | 20 | 10 | 28 | 14 | 40 | 26 | 34 | 28 | 31 | 33 | 32 | 22 | 20 | 10 | 20 | 10 | 28 | 1 | 32 | 16 | 26 | 24 | 32 | 20 | 30 | 16 | 30 | 26 | 28 | 26 | 32 | 26 | 32 | 24 | 18 | 10 | 12 | 8 | 2 | -10 | .. | .. |
| Jan..... | 6 | -12 | 20 | 6 | 30 | 8 | 20 | 10 | 32 | 18 | 32 | 20 | 32 | 22 | 20 | 4 | 20 | 2 | 32 | 30 | 24 | 18 | 18 | 12 | 34 | 18 | 36 | 28 | 10 | 2 | 28 | 16 | 30 | 24 | 24 | 10 | 32 | 18 | 25 | 20 | 28 | 18 | 22 | 14 | 16 | 4 | 18 | 6 | 20 | 8 | 12 | 8 | 6 | 0 | 8 | 0 | 18 | 4 | 12 | 6 | 14 | 4 |
| Feb..... | 16 | 4 | 0 | -10 | 8 | -4 | 16 | 6 | 22 | 10 | 28 | 14 | 30 | 18 | 38 | 16 | 42 | 36 | 46 | 40 | 46 | 34 | 31 | 30 | 32 | 28 | 30 | 14 | 26 | 10 | 42 | 20 | 30 | 16 | 30 | 18 | 34 | 28 | 30 | 16 | 31 | 22 | 30 | 14 | 35 | 20 | 4 | 6 | 16 | 0 | 18 | 0 | 46 | 32 | 46 | 40 | .. | .. | .. | .. | .. | .. |
| March.. | 40 | 36 | 32 | 24 | 34 | 32 | 36 | 32 | 32 | 24 | 34 | 30 | 42 | 24 | 38 | 24 | 36 | 32 | 38 | 36 | 30 | 24 | 38 | 22 | 40 | 30 | 40 | 30 | 40 | 30 | 40 | 30 | 40 | 30 | 40 | 30 | 44 | 30 | 34 | 32 | 36 | 30 | 38 | 30 | 34 | 24 | 36 | 24 | 36 | 26 | 30 | 24 | 30 | 22 | 34 | 24 | 36 | 24 | 32 | 30 | 30 | 28 |
| 1881-82. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec..... | 56 | 46 | 37 | 28 | 38 | 30 | 34 | 30 | 37 | 28 | 39 | 24 | 42 | 38 | 32 | 24 | 40 | 28 | 27 | 12 | 22 | 6 | 34 | 18 | 50 | 38 | 58 | 46 | 32 | 18 | 18 | 4 | 30 | 20 | 40 | 30 | 38 | 24 | 37 | 34 | 38 | 30 | 48 | 34 | 50 | 30 | 20 | 12 | 35 | 20 | 44 | 34 | 48 | 42 | 42 | 38 | 46 | 40 | 36 | 32 | 30 | 26 |
| Jan..... | 28 | 22 | 10 | 8 | 18 | -4 | 14 | -4 | 16 | -2 | 24 | 16 | 32 | 30 | 32 | 18 | 44 | 34 | 34 | 30 | 32 | 22 | 34 | 20 | 30 | 18 | 30 | 20 | 28 | 20 | 38 | 30 | 20 | 4 | 20 | 8 | 30 | 26 | 30 | 10 | 35 | 28 | 32 | 10 | 0 | 6 | -6 | -18 | 22 | 0 | 38 | 35 | 40 | 32 | 30 | 20 | 22 | 10 | 20 | 8 | 30 | 10 |
| Feb..... | 28 | 18 | 32 | 20 | 28 | 12 | 12 | -2 | 20 | 8 | 21 | 8 | 30 | 14 | 32 | 26 | 40 | 20 | 32 | 28 | 22 | 16 | 36 | 24 | 44 | 32 | 38 | 32 | 43 | 30 | 50 | 30 | 44 | 24 | 14 | 0 | 22 | 10 | 36 | 26 | 30 | 20 | 30 | 18 | 20 | 6 | 28 | 8 | 30 | 10 | 34 | 16 | 38 | 32 | 44 | 30 | .. | .. | .. | .. | .. | .. |
| March.. | 48 | 30 | 44 | 42 | 44 | 36 | 38 | 32 | 46 | 30 | 42 | 36 | 30 | 28 | 30 | 12 | 32 | 20 | 44 | 34 | 36 | 26 | 38 | 28 | 35 | 29 | 24 | 16 | 28 | 12 | 32 | 22 | 32 | 22 | 30 | 18 | 40 | 28 | 48 | 30 | 30 | 30 | 40 | 24 | 32 | 20 | 32 | 24 | 22 | 10 | 32 | 18 | 48 | 38 | 38 | 34 | 38 | 22 | 40 | 33 | 28 | 22 |
| 1882-83. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dec..... | 30 | 20 | 40 | 30 | 18 | 10 | 18 | -2 | 38 | 28 | 44 | 35 | 38 | 11 | 14 | 10 | 18 | 10 | 30 | 20 | 28 | 24 | 20 | 10 | 34 | 14 | 24 | 22 | 22 | 14 | 14 | 10 | 22 | 10 | 24 | 12 | 18 | 8 | 22 | 14 | 32 | 22 | 32 | 28 | 33 | 22 | 32 | 28 | 33 | 28 | 30 | 22 | 32 | 20 | 24 | 18 | 24 | 10 | 30 | 13 | 32 | 20 |
| Jan..... | 24 | 10 | 30 | 18 | 30 | 2 | 18 | 10 | 10 | 0 | 10 | 2 | 26 | 10 | 26 | 13 | 22 | 10 | 9 | 4 | 12 | 4 | 8 | 2 | 32 | 6 | 36 | 20 | 20 | 4 | 26 | 6 | 28 | 8 | 30 | 26 | 29 | 8 | 30 | 18 | 38 | 18 | 8 | 2 | -1 | 8 | 16 | 4 | 20 | 16 | 18 | 6 | 32 | 18 | 36 | 32 | 32 | 26 | 32 | 25 | 36 | 32 |
| Feb..... | 24 | 14 | 20 | 6 | 24 | 16 | 42 | 26 | 25 | 16 | 22 | 4 | 34 | 24 | 23 | 10 | 28 | 16 | 11 | 0 | 31 | 10 | 27 | 16 | 28 | 8 | 30 | 17 | 26 | 16 | 38 | 24 | 48 | 36 | 24 | 18 | 30 | 14 | 30 | 6 | 20 | 16 | 30 | 16 | 24 | 12 | 30 | 6 | 42 | 30 | 27 | 20 | 12 | 4 | 24 | 17 | .. | .. | .. | .. | .. | .. |
| March.. | 30 | 10 | 46 | 34 | 30 | 18 | 20 | 2 | 8 | 4 | 20 | -2 | 20 | 10 | 10 | 8 | 20 | 4 | 38 | 20 | 30 | 16 | 24 | 0 | 30 | 22 | 36 | 10 | 40 | 28 | 16 | 10 | 32 | 10 | 48 | 30 | 39 | 28 | 34 | 20 | 26 | 11 | 20 | 8 | 28 | 10 | 29 | 10 | 36 | 18 | 44 | 28 | 36 | 33 | 35 | 28 | 32 | 18 | 36 | 24 | 36 | 18 |

degree above the freezing point, so that whatever frost had penetrated the ground during the short cold period would undoubtedly be removed long before the twenty days expired. In fact there could have been very little severe frost after this time, for the average temperature of the month of February following was 28 degrees Fahr., while March had an average of 34 degrees Fahr.

It is true that here in New England extremes of cold are followed frequently by warmer periods, that is, the weather is not excessively cold for long periods of time, but the reaction is not generally great, and it is almost too well known a fact to be commented upon, that after the frost once enters the ground here, it stays with almost constantly increasing depth until spring fairly opens.

That this difference in climatic conditions is likely to prove a troublesome matter, if any method of land treatment is exclusively relied upon, there would seem to be but little doubt.

Whether the excessive cold of our New England winters would prove to be an insurmountable obstacle to this method of sewage disposal, can only be determined by experiments extending over a series of years. The fact that there may be some difficulty has been recognized in reports made upon the subject by experts employed by the State.

The Commission appointed by the State Board of Health in 1881, consisting of Charles F. Folsom, M.D., Joseph P. Davis, M. Am. Soc. C. E., and Henry P. Walcott, M.D., after carefully investigating the subject, say in their report to the Board:

"Considering the extreme heat and cold of the climate, the heavy rainfall, and the great dilution of the sewage, the difficulties in the way of a satisfactory disposal of the sewage of Worcester are far beyond those of any other town where the question has been met, so that any scheme that may be proposed may be said to be experimental to a certain extent, and to be successful, and not create a greater nuisance than it abolishes, it must be costly in the original outlay and involve also a considerable yearly expense."

Mr. Eliot C. Clarke, M. Am. Soc. C. E., in his report to the Commission appointed by the Governor under an Act of the Legislature, in 1884, says on page 133, after discussing the different methods employed abroad for sewage purification:

"Almost all the examples of sewage treatment on which the foregoing statements are based occur in England. The conditions, climatic and other, existing in Massachusetts are somewhat different from those in England. How far this difference of conditions might affect the choice of methods of disposal here, can only be definitely learned by experiment."

It would certainly seem from the above statements that the persons making the reports referred to had some doubt as to the successful working of any scheme of land purification, although they recommended downward intermittent filtration.

The sewage farm at Pullman, Ill., has frequently been cited as being a place where successful purification of sewage is accomplished in the winter, in a climate similar to that of New England.

In order to fully satisfy myself as to the fact, I visited Pullman in January of the present year.

The farm has an area of about one hundred and forty acres, nearly all of which is devoted to irrigation; there are ten acres, however, set apart for a filtration area, this being thoroughly underdrained, the drains being about twelve feet apart.

Upon the day of my visit it was quite warm, the thermometer registering forty degrees Fahr. I found that the sewage was all being discharged upon the filtration area, the first section of which was covered with sludge to a depth of about a foot. The sewage was running over this, to the second section which was partially covered with ice, and then over the remaining area which was entirely covered with ice, and was finally discharged into the effluent trench without having been filtered in the least.

I was told that not a particle of sewage has been applied to the farm proper during the winter, it all having been simply passed over the area as already described.

Mr. B. S. Brundell, C. E., M. Inst. C. E., one of the ablest sanitary engineers in England, and a gentleman who has constructed many sewage farms, among the number, the farm at Doncaster, which is one of the most successful farms in operation (from a sanitary point of view) in England, says in a letter to me on the subject:

"Our winters here, although adding to the trouble of sewage irrigation, do not make it impossible. The temperature of the sewage, when it reaches the land is sufficiently high to keep the outfalls open; but of course when it spreads upon the land it soon becomes frozen, and remains a glazed surface until the thaw sets in when it is gradually absorbed by the land.

"I do not feel able to give an opinion as to how far this process would be limited by the degree of cold to which you are liable, but I foresee very considerable difficulty in the matter."

Mr. James Mansergh, C. E., M. Inst. C. E., in answer to a similar inquiry, says:

"I have carefully considered, in the light of my experience in England, whether under such conditions as these, the disposal of sewage by way of broad irrigation and downward intermittent filtration may be counted on as a reliable and satisfactory mode of treatment. I have heard that, in the severe winters we have had here since 1878, it has been with some difficulty that trouble has been avoided on more than one farm.

"Under the conditions you have described to me, I should have very great hesitation in recommending the process of broad irrigation and intermittent filtration as reliable modes of disposing of the sewage and preventing the pollution of the river.

"I should fear that during such frosts, as you tell me not unfrequently prevail, the ground would get frozen so hard as to render it impervious to the sewage which would then simply flow over the surface into the river or its tributaries in a crude condition.

"In order to acquaint myself more particularly with the relative temperatures at Worcester, U. S., and England, I have obtained certain statistics from Mr. G. W. Symonds, F. R. S., which I have embodied in the accompanying diagram."

I will not show Mr. Mansergh's diagram here, but will simply say that it shows the difference in temperature between Massachusetts, England, and Germany, the figures corresponding very closely with those given above. In conclusion he says:

"All these figures confirm me in my opinion that it would not be prudent to trust to getting rid of sewage satisfactorily at Worcester by the irrigation process."

The great difference in the amount of annual rainfall is also an important factor to be considered. The greatest rainfall given at any place visited was at Wigan, where the average is about forty inches per annum, while the smallest amount was at Barnsley, where the average was given as $28\frac{6}{10}$ inches per annum. The average of all places visited was 34 inches per annum.

At Worcester the average is about forty-eight inches per annum, the lowest recorded amount for one year being 34.5 inches, or about the same as the average amount at the places where inquiry was made, while the greatest recorded rainfall for one year at Worcester is 61.48 inches.

Now it is generally the experience abroad that during storms the sewage has to be disposed of in some other way than by irrigation, the ground being frequently surcharged with water, rendering it incapable of purifying the sewage at all. With the large rainfall here, this difficulty would be very much increased.

Aside from the difficulties caused by climatic differences, there is still another objection to irrigation in the case of a city or town

situated as Worcester is, at the head of a large manufacturing stream, where every drop of water running in the river is utilized for power. I refer to the loss of water by this means of sewage disposal. Just what the amount would be that the vegetation would absorb, and that would evaporate, can only be determined by actual trial.

At Berlin, the experiments show that at least 30 per cent. is retained, while at Doncaster most of the water is lost in this way, the reason being that only a small quantity of sewage is applied to any one piece of land, the intention being not to apply more than would come in an ordinary rainfall. That the loss of water would be considerable, there can be no doubt.

The above are the principal objections to irrigation so far as localities similar to central Massachusetts are concerned. While they are more or less local in their character, there is danger that by the adoption of irrigation, especially when a large quantity of sewage is to be treated, the irrigation fields will become a greater nuisance than the one which is to be abated. In other words, it takes the most careful management to prevent a sewage farm from becoming offensive.

My own observation was, that at about one-half the places visited, more or less odor was noticeable. The weather was quite favorable, however, it being in the fall.

The great danger here would be with the greater amount of heat in the summer, and great care would have to be exercised to prevent more sewage being applied to the land than would be readily absorbed.

That this trouble is recognized in England, the report of the Royal Commission on Metropolitan Sewage Discharge, for 1884, will show.

I will not attempt to quote from that report here, but there is abundant testimony that the irrigation fields, especially when they are located near dwellings, are at times very offensive.

What has been said in relation to treating sewage by irrigation, applies also to downward intermittent filtration, so far as the effect of the climatic and other conditions are concerned; in some respects, however, not to so great an extent; for instance, the amount of water lost by evaporation and absorption would not be as great, the effect of severe frosts would probably be about the same, as in order to obtain an effluent that is at all satisfactory the application (as the name of the system implies) must be intermittent; it will not do to simply turn the sewage constantly over a single area of underdrained land and expect

that a clear effluent will be obtained ; the land must have rest. "The intermittency is a *sine qua non* even in suitably constituted soils, whenever complete success is aimed at." The danger would be that after one filtration area has received all the sewage that can be applied at one time, and before the relatively warm sewage can be again applied (generally after three or four days), the ground would be frozen to such an extent that filtration would not take place.

The temperature of the sewage has therefore much to do with the length of time that the ground can be kept open, and also with the extent of the area upon which sewage can be applied in cold weather. There were only two places that I visited where a record had been kept of the temperature of the sewage, viz., at Berlin and Paris. At the former place the lowest temperature reached in winter was 45 degrees Fahr., while at the latter place the minimum was 41 degrees Fahr. At Pullman there has been no record kept, so I was told, but the sewage must be very warm, as the "separate system" of sewers is in use, and nothing but house drainage is allowed to enter the sewers, all surface water being excluded.

At Worcester the sewers have all been constructed to receive drainage of every nature. All surface water is conducted to them, and in consequence the temperature of the sewage is at times very low. The record shows that in the main lateral sewers as low as 33 degrees Fahr. is reached. It is probable therefore that sewage taken from them and applied to the land would freeze quickly and could not be depended upon to keep the ground free from frost.

The advantage that intermittent filtration would have over broad irrigation, is that a much smaller area of land would be required, and the raising of crops would have to be made of secondary importance. In fact it would be much better not to attempt to raise crops at all, as the income derived therefrom would be small, and the tendency would probably be to neglect the purification of the sewage in order to derive as large an income as possible from the land.

It must be understood that in order to obtain a good effluent, especially when the area of land is limited, some means of separating the sludge from the sewage is almost absolutely necessary to prevent the ground from clogging. This fact is recognized by English authorities and, as before shown, this method of sewage treatment has been rarely used except as an auxiliary to irrigation or precipitation.

Chemical precipitation would not be subject to the objections spoken of above, and where the sewage has to be treated constantly, through the entire year, would seem to be a method that presents many advantages. Much depends, however, upon the conditions that exist in different localities. No fixed rule can be laid down as the only one to be followed, but the solution of the method to be used, must be determined, it seems to me, only after a most careful and conscientious study of existing circumstances. For the City of Worcester I have recommended chemical precipitation, with the possible addition of a filtration area, to be used in connection with the precipitation works during the summer months.

## DISCUSSION ON SEWAGE DISPOSAL.

ELIOT C. CLARKE, M. Am. Soc. C. E.—I fear I cannot add much to what has been presented ; but as the sewage-disposal works at Medfield, designed by me, have been referred to, I will give a brief description of them. The state of things which called for some remedy was this : Medfield is a country village with a single large factory where straw braid is sewed, dyed and shaped into hats and bonnets. Through the village flows a brook into which the factory and also some of the houses drained. This brook was thus rendered very foul and offensive. The greater part of the pollution was due to the factory drainage, which, roughly estimated, amounted to 36 000 gallons a day. Abutters on the lower part of the brook made frequent complaints, and threatened suits and injunctions. It was feared that the factory would be closed or be driven from the town. The problem was : to dispose of the factory sewage without causing any nuisance and without polluting Charles River, in whose watershed Medfield lies, this river being used below as a source of domestic water supply. What was done was this : A drain was built, extending from the factory, about a mile, to a tract of gravelly soil on the outskirts of the village, where a square acre was prepared as a filter bed, and the sewage disposed of upon it by intermittent filtration.

A MEMBER.—How large was the population ?

Mr. E. C. CLARKE.—Five hundred operatives are employed in the factory, and the water closets used by them connect with the sewer. About half a dozen houses also are at present connected. Medfield has no other sewers ; but when any are built, this one can be used as an outlet for them. Then the filter beds may need to be enlarged. At present the chief source of pollution in the sewage is manufacturing refuse from the factory. Some of this refuse, as, for instance, the ground dye woods, might have caused trouble by settling in the sewer and clogging it. To prevent this, such matters are arrested by subsidence and filtration at the factory, before the waste water containing them is admitted to the sewer. This is done by causing the sewage to flow first through a large tank, divided into several compartments by bridge walls, over which the sewage flows. In these compartments much of the bark settles. In the last compartment is a large mattress of excelsior through which the sewage is made to filter upwards, by which all but the finest particles are intercepted.

Still the sewage is very dark colored and foul looking when it reaches the filtration area. This area is nearly square, an acre in extent, and is divided by two low banks bisecting it at right angles to each other, into four square quarters of an acre. The sewer ends at the middle of the large area and its outlet is so arranged that the sewage can be turned upon any one of the four quarter-acre plots. It has been the practice to let the sewage run for two days upon one plot, then change it for two

days to the next plot, and so on to each in rotation. Thus each plot receives the sewage for two days and rests for six days before receiving its next dose.

The works were completed and filtration began in November, 1886, just before the advent of freezing weather. As is usual in such cases, the selectmen and other inhabitants of the town predicted dire results as sure to be caused by the effect of frost on the sewage and the filter beds. The first winter was a cold one; 13 degrees below zero Fahr. was noted one day at the filtration area, but there was no trouble on that account. A thin sheet of ice formed, but the sewage flowing beneath it thawed the ground and filtered through it.

This area is not underdrained. It was important to avoid all unnecessary expense, and as the soil was very porous and the ground water low, I thought drains could be dispensed with, as proved to be the fact. Consequently, the immediate effluent from the filter beds cannot be seen. It appears, however, a short distance away. The filter beds were graded on sloping land, and at the bottom of the slope, a few hundred feet from the beds, is a flowing spring which undoubtedly receives all of the filtered sewage. The flow from the spring has about doubled since the works went into operation, and the water is just as limpid and tastes as well as it did before. No one drinking it would suspect that it was not good clean spring water.

I wish we might rid ourselves of this bugbear of the injurious effect of frost upon sewage disposal. The Pullman works are instructive on this point. There 800 000 gallons of sewage a day are disposed of, and in the winter it is turned upon two or three acres of filter beds which are used for months at a time. Of course that is too long a period to produce good results and the surface of the ground becomes clogged by sediment; but the ground does not freeze. I once visited the Pullman works in winter when the weather had been very cold. For about a week the mercury had been below zero. It had been as low as twenty degrees below, and on the day of my visit registered twelve below. The ice on the surface of the sewage, in places, was 10 inches thick. I cut a hole through it and found the ground beneath perfectly open. The sewage was filtering through the ground without regard to the frost. There was too much sewage for the area of land used and the effluent was quite dirty. The soil at the Pullman farm is not suitable for purifying large quantities of sewage. From my own experience: given good, porous, gravelly land, such as we had at Medfield, I would not be afraid to apply 100 000 gallons of ordinary sewage to each acre throughout the year. There would be no danger of the soil clogging in time. At Medfield, as at other filtration areas I have seen, the solid particles in the sewage form a thin deposit, entirely upon the surface of the ground. They do not penetrate it at all. By leaving the land unused for a few days this thin scum of deposit dries, cracks and curls up in detached

pieces. When too much of it has accumulated, it can be raked off of the surface of the ground.

I have visited from twenty to thirty sewage-disposal works in England and I thought that the most successful ones were those which practiced intermittent filtration. When this method was not successful it seemed to be due to the fact that the primary object, *i. e.*, the purification of the sewage, was interfered with by an attempt to make money by cultivating the filtration areas.

L. B. Ward, M. Am. Soc. C. E.—I would like to ask what were the results of your observation in regard to the sense of smell?

Mr. E. C. Clarke.—At well-managed sewage farms there was little, if any, smell. Some of the English farms are very large, and the farmers and laborers, with their families, live in cottages surrounded by the irrigated fields. Neither adults nor children seem to suffer thereby. I noticed the children especially, and they looked as sturdy as any that I saw elsewhere. On muggy days, when the air is heavy, and everything which can give out a smell does so, a slight odor will be noticed at even a well-managed farm. But it is not a strong nor an offensive odor and people do not seem to mind it. The Vice-President of the Pullman Company lives contentedly in a very handsome house within a few hundred feet of the sewage farm. Mr. Martin, the Superintendent of the farm, with his family, lives in a nice house situated near to the center of the farm. He says that he is not troubled by any offensive odors. There is a village growing up on land contiguous to the farm. Certainly people would not settle there and build houses if they were exposed to bad smells. The fact is, that fresh sewage applied promptly to land in a thin sheet does not give off any bad smell; but if it is permitted to stand stagnant in a ditch or pool until it putrifies, it becomes offensive. Ditches therefore are to be avoided in connection with land purification. It is better practice to draw the sewage upon the land from hydrants or from smooth channels, elevated above the general surface of the ground. With such precautions and with soil of suitable character, sewage filtration can be carried on without risk of causing any nuisance.

A Member.—What is the depth of the sewage on the Medfield quarter of an acre filter beds? What is the depth of the sewage deposited on them?

Mr. E. C. Clarke.—It cannot be said that there is any depth to the sewage, because no one of the quarter-acre plots has ever been entirely covered. That is, the sewage sinks into the ground before reaching the farther side of the plot. The farthest point ever reached by the sewage in flowing, before it sinks into the ground, is readily determined, because the sewage is full of dye stuffs and discolors the gravel surfaces of the beds wherever it reaches them. Roughly speaking, about one-half of each bed shows such discoloration, or did so the last time I saw them.

A MEMBER.—Do you remember the depth of the gravel bed?

Mr. E. C. CLARKE.—It is a natural gravel formation and I do not know its depth. I had a pit dug from eight to ten feet deep to determine the elevation of the ground water. To that depth the character of soil was uniform, consisting of pebbles of various sizes, the interstices being filled with coarse sand. If the soil water had been less than eight feet below the surface under-drainage might have been necessary.

A MEMBER.—It has a sloping surface?

Mr. E. C. CLARKE.—The land was inclined, but we graded it to a nearly level plane. We made the center of the large area, where the sewer outlet is, a little the highest, so as to cause the sewage to flow over the beds. The inclination downwards from the point where the sewage enters a bed is about six inches in a hundred feet.

J. S. SCHAEFFER, M. Am. Soc. C. E.—There are many systems where you admit all the drainage water directly into the sewers?

Mr. E. C. CLARKE.—You cannot have a perfect system of purification where you admit surface water into the sewers. Of course, during dry seasons such a system will work as well as any other, there being nothing but the ordinary sewage proper to be disposed of. But when the sewers are flowing full with rain water, the amount of sewage will be too great to be adequately treated in any way. At such times the greater part of it must overflow into the water-courses. It will be so dilute that usually no nuisance will be caused by such occasional overflow and if it is only necessary to avoid causing a nuisance such a system will be proper. But when there are legal restrictions or other reasons against discharging *any* sewage without purification, this can only be accomplished by building a separate system of sewerage.

Mr. SCHAEFFER.—I would like to ask whether the water has been chemically analyzed?

Mr. E. C. CLARKE.—The State Board of Health made an analysis, but I have not seen the result. I understand that it showed marked evidence of previous sewage contamination, but also showed that all organic matters had been changed into harmless products, and that the water was entirely potable.

Mr. WARD.—Where this sewage is used on the farms, what is your information in regard to the quality of the vegetables?

Mr. E. C. CLARKE.—I only know what I have been told. At the market gardens, near Paris, which are irrigated with sewage, they said that the vegetables were greatly improved, and were in much request at the clubs. Mr. Martin, the Superintendent of the Pullman farm, tells me that he gets the finest celery to be found anywhere. It may well be so. There are farms in the vicinity of Boston devoted to raising garden truck where during certain seasons of the year, water for irrigation is purchased at the rate of two cents per one hundred gallons, and is used at the rate of 500 000 gallons a day. For this purpose sewage, unless it contained too

much manufacturing refuse ought to be worth as much as pure water, or a little more. At the Pullman farm, sewage is only applied to such vegetables as will be benefited by it. Potatoes never receive any of it. This farm is said to clear a profit of $5 000 a year, which does not seem to be very much for a farm of its size. Still Mr. Martin thinks that having the sewage water to use whenever it is needed, is of great advantage to him. I understand that loamy and clayey soils are somewhat more benefited by the application of sewage than are sandy soils. Perhaps this is because they are more rich in humic acids which fix and retain the ammonia contained by the sewage. A clay soil, however, can dispose of so little sewage that it is necessary to use a very much larger area of it.

A Member.—How much?

Mr. E. C. Clarke.—It depends entirely upon the character of the soil. I cannot say exactly; at least ten times as much.

F. P. Stearns, M. Am. Soc. C. E.—There is one point which I think deserves consideration in connection with the question of the winter disposal of sewage upon land, and this is the temperature of the sewage. This, in many cases, depends chiefly upon the temperature of the water supply.

In Boston the water drawn from the pipes in winter has a temperature of 37 degrees, and the sewage as it enters the reservoir of the main drainage works is at 43 degrees. Late in the autumn or early in the spring when the water is somewhat warmer, the sewage is also warmer by about the same amount.

Water taken from Massachusetts rivers, when covered with ice, is very near the freezing point; while, on the other hand, water drawn from a well or other ground-water source has, even in winter, a temperature of about fifty degrees.

In the coldest weather in winter I have observed the temperature of sewage discharged upon a disposal area at one public institution to be 41 degrees, at another 51 degrees, while in another instance in which the water supply comes from the ground and the sewage is warmed to a considerable extent by the discharge of hot water from a factory, the temperature is as high as 60 degrees.

While it is probable that the coldest sewage may be disposed of upon land in winter in this climate, such disposal may be more confidently advised where the sewage is warmer, and in seeking for precedents it is desirable to know the temperature of the sewage as well as the severity of the winters.

Robert Moore, M. Am. Soc. C. E.—I think, Mr. President, this trouble which Mr. Allen speaks of, of danger of failure from cold weather, if it were a real one, would occur in the winter. In very cold weather, when the windows are closed there would be no incon-

venience caused by it. If the sewage were turned into the streams so that no decomposition takes place, the conditions which would cause a nuisance would be absent. I think, at Pullman, there is no trouble at all in the winter. The sewage itself is of a comparatively inoffensive character, but the whole process is conducted so carelessly that if any trouble would arise anywhere it would arise there.

Emil Kuichling, M. Am. Soc. C. E.—It is a matter of some importance in this discussion to draw a line of distinction between the uses to which the effluent is put. It has been found, I think, by recent investigations in England and elsewhere, that the filtration of sewage through gravel is simply a mechanical separation or removal of the particles held in suspension, and that no appreciable portion of the matter in solution is removed thereby; hence, if the effluent is to be admitted into a stream from which water is to be taken for drinking purposes, the quality of the effluent is a thing to be very carefully considered. This is to-day, a matter of very serious consideration, even in places where the filtration takes place through fine sand, or sandy loam. Perhaps the most extensive recent investigations of this kind are those conducted by Professor Alexander Müller, of Berlin, who was connected with the sewage commission of that city, and the investigations made by him led to the conclusion that the subsoil water might become seriously polluted by the percolation from a sewage farm. In 1885 Professor Müller submitted a report to the German Agricultural Council, in which serious attacks were made on the quality of the effluents from the Berlin sewage farms, a portion of which goes into the River Spree, above the water-works' intake. In this investigation it was found that a contamination of the subsoil water had actually taken place. The soil on these farms and vicinity, for miles in extent, is a fine sandy loam of indefinite depth.

Professor Müller states that when such lands are heavily irrigated, the amount of organic matter conveyed by the sewage may easily reach a limit which threatens not only the existence of the food-plants growing upon the surface, but also that of the nitrifying ferments or organisms contained in the soil. Under these conditions, the tendency is to bring about a slow putrefaction of the organic substances, with the development of products of a more or less noxious character, instead of the desirable rapid decomposition or nitrification. The excess of soluble organic matter must accordingly pass into the ground water, where it serves as nutriment for a different class of microbes, whose presence or development may perhaps be very undesirable when such water is used for drinking purposes. Some of these products of putrefaction are, moreover, known to be active poisons, and should therefore be excluded as far as possible from subterranean water supplies. Difficulties of this kind are liable to occur when large volumes of sewage are fil-

tered through very porous soils of considerable depth, and the pollution of the subsoil water has been traced for long distances beyond the boundaries of the filtration area. Care should accordingly be taken to locate the sewage irrigation fields in places where it can be reasonably well demonstrated that the ground water soon finds its way into a natural stream, where the process of nitrification of the dissolved organic matter can be completed after a run of a number of miles, freely exposed to the action of the atmosphere.

Now, in discussing the subject of sewage disposal by irrigation or filtration, the important point to be borne in mind is the amount of liquid to be dealt with. From this only can the reduction to number of persons per acre per year be made. The estimates found in professional literature, however, are usually given in the latter form, and are therefore very often misleading, inasmuch as they always refer to rates of water consumption which are much less than what we find to be the case in American cities. The use of water in English and European cities ranges from 30 to 60 gallons per head per day, while we have here a consumption of from 60 to 150 gallons, of which a large proportion is waste; but everything is sewage which issues from the sewers, and therefore, in the consideration of sewage-disposal projects for our cities, the area required for irrigation or filtration must be correspondingly increased above the estimates based upon the foreign rates of water supply. The recognition of the influence of variability of the use or waste of water in different places has latterly led to the introduction of a new and better standard for estimating the required area of land, and which is based upon the weight or volume of sewage that can be thrown upon an acre of land per day or per year. If I remember right, the evidence given recently before the investigating commission on the discharge of the sewage of London indicated that for securing a good effluent from a sewage farm, we should not have more than about 1 500 tons of water or liquid per acre per year. This means about 1 100 United States gallons per acre per day; and if we reduce this to the other usual standard, we see that with a water supply or sewage production of 100 gallons per head per day, one acre of land will be required for the sewage of only eleven persons. The usual estimate found in manuals and reports is, however, that in broad irrigation one acre of land can take care of the sewage of from one hundred to two hundred persons without causing nuisance; and if this were to be applied with the sewage of our cities, we should have a weight of from 13 570 to 27 140 tons of liquid per acre per year. But for agricultural utilization of sewage on sandy soils, English authorities recommend that a maximum of from 5 000 to 10 000 tons should not be exceeded; hence it follows that for American conditions, we must estimate that the area of land required for broad irrigation is two or three times more than what is required abroad.

Sanitarians, on the other hand, demand a large reduction of the quantity of sewage allowed to flow upon land, holding that about three hundred tons per acre per year, or about 230 gallons per acre per day, should not be exceeded in order to comply with the two important sanitary conditions, namely: freedom from stench nuisance, and the avoidance of subsoil-water pollution. Where the slightest trouble from the failure to meet these conditions occurs, bitter attacks upon the farm and its management have invariably followed. Especially was this the case in Berlin, where they commenced the sewage irrigation on a basis of two hundred and fifty persons per acre, reducing year by year to two hundred, one hundred and twenty and one hundred persons per acre, in proportion as the acquired lands were adapted to irrigation. In the spring of 1884, I visited the two large sewage farms, measured by thousands of acres, which are owned by the City of Berlin. The director of the farms, a highly cultivated gentleman, stated that the tendency was to still further reduce the amount of sewage put upon land; he hoped to get it down to a basis of seventy-five persons per acre per year; but preferred to reduce it to fifty, but could not try it just then. By such a reduction they hoped to make a slight profit; also, "*sub rosa*," to do away with the alleged pollution of the subsoil waters and effect the abatement of the stench nuisance that occurs on all sewage farms and at pretty much all seasons of the year. During the winter and spring of 1883–84, I visited over thirty different sewage farms in Europe. The season was unusually mild, and nowhere was there any snow on the ground; but on all of these farms there was a marked odor which many would pronounce offensive.

Now, a question arises here which we are bound to take into consideration, in view of the unsettled condition of our laws relating to health, and that is: what punishment is a municipal corporation likely to suffer by creating a nuisance upon a sewage farm or sewage purification works? It is pretty well known to engineers that in all questions relating to interference with streams the only safe rule is "Hands off," that is to say, do not tamper with them in any way. We have perhaps an illustration of this doctrine in the case of the City of Rochester, where, at the present time, about one hundred and fifty suits for damages are pending, by reason of the pollution of several small natural water-courses through the discharge of raw sewage, and where almost every suit results in a verdict for the plaintiff. In this litigation the policy of the City of Rochester is simply to gain time by carrying these suits to the Court of Appeals. For years the construction of a suitable intercepting sewer has been agitated, but hitherto the fact has been that the interest on the cost of such a large sewer was much more than the damage which the juries have awarded to the farmers. The tendency of the juries is now, however, to gradually raise the amount of damages, and the time will soon come when the annual sums thus

awarded will exceed the interest on the cost of the contemplated sewer, whereupon its construction will doubtless be commenced. As a matter of fact, only a small amount of nuisance is occasioned in the most of these water-courses; but if the relatively slight nuisance resulting from the pollution of a little brook flowing through a farm is valued by our courts at appreciable sums every year, we may well be apprehensive of the results that would probably follow in the case of a badly planned or improperly managed large sewage farm or precipitating works.

At the great Berlin farms the sewage can at times not only be smelled at the distance of nearly half a mile, but it can also be tasted in the atmosphere. The same condition of things was likewise observed at a number of English farms. If we take into account all the complications resulting from the unsettled condition of our health laws and from the changes involved by our political system, I presume that the best method of treating sewage on a large scale is by some chemical process, combined with a filtration of the clarified effluent either through natural or artificial filters; and then, if the effluent is to be turned into a stream whose water is used for drinking purposes, there is less danger of infection.

A matter of considerable importance in this chemical treatment is the rate at which the sewage flows through the tanks. The most consistent of all the statements that I have found after considerable study of the subject is that given by Dr. Tidy, in which he states that two tanks should be used, the first one of such capacity as to receive at least one hour's discharge of sewage, while the second should hold at least four hours' flow after having passed through the first tank. From this formula the actual size of the tanks can be determined, it having been found by experience that the depth of the water therein should be from 5 to 6 feet. The general practice in England is to make the tanks with sloping bottom, the average depth being about 6 feet. With small tanks a more frequent removal of the sludge becomes necessary. The rate of flow through a series of tanks worked continuously is always quite small. With regard to discharging the effluent, it flows in a thin sheet over a long weir, and wherever possible, it is allowed to fall in a series of small cascades. The thickness of the sheet of liquid is generally about one-half an inch, and I can say from what I have seen of some of these chemical processes that the effluent is very good. Particularly is this true of the "A B C Process" at Aylesbury in England.

In regard to the matter of fish living in water polluted by organic matter, I was informed recently by a well-known pisciculturist that, for most varieties of fish, purity of the water is not so much an essential factor as freedom from suspended matter and temperature; that even the brook trout, which is popularly supposed to be a fish that can live only in the purest water, is in reality not a very delicate or fastidious animal, inasmuch as it can endure considerable occasional roiliness and pollution

of water by organic matter of both animal and vegetable origin ; but that on the other hand the brook trout must have a low temperature, which is the more important condition for its existence. I asked the gentleman to make some experiments on this subject with both raw and clarified sewage, but thus far he has not had the opportunity to do so, and hence no definite conclusions can be given. The effect of certain gases, salts and acids upon fish has, however, been carefully studied by Professor C. Weigelt, who has published the results arrived at in the "Archiv für Hygiene" for 1885.

It is therefore a popular fallacy that water in which brook trout will live is necessarily pure and fit for human consumption, since in many instances this is not the fact. The same is also true of the various forms of plant life. It does not follow, because certain plants, such as water-cress, grow in a stream of running water, that such water is pure ; the element of temperature, and the amount and kind of mineral matter in the water, both play an important rôle.

In regard to the aeration of the soil and the intermittence of the application of sewage, the observations that I have made in examining sewage farms agree with those of Mr. Allen. The surface of the land becomes to some extent clogged with matter of various kinds, forming a slimy coating which must be occasionally broken up by suitable cultivation. This is true both of broad irrigation and filtration wherever unsedimented sewage is applied. To insure a penetration of the liquid into the soil, the surface must either be worked, or else be given time to effect the destruction of the intercepted matter by natural processes, and hence an intermittence of action is indispensable in order to secure proper purification.

It may also be of interest to mention that in sandy soils which have been specially prepared for filtering sewage, the under-drains frequently become clogged or obstructed by the growth of a peculiar alga, or fungus, which has been called the sewage fungus. It grows in thick masses, colored yellow, orange, red, brown, or white, depending upon the character of the mineral salts dissolved in the sewage, and its function is to transform the organic matter which is held in solution in the effluent. Its presence is therefore always an indication of incomplete purification ; and it was rarely absent from the effluent drains and ditches of the various sewage farms which I had the opportunity of visiting.

In refutation of what has been said with regard to the sanitary condition of sewage farms and their pollution of the subsoil water, as reliable evidence can be adduced as can be brought for the opposite side. The Paris Commission which was instituted for the investigation of this matter, state that there is a constant odor rising from the farms due to the disposal of sewage by irrigation. Other equally reputable physicians and sanitarians think they have proven the contrary. I had in my pos-

session a report giving very favorable statistics of sickness among the laborers upon these farms; but it must be remembered that a process of natural selection takes place in the choice of such laborers, since there is a general feeling abroad that a sickly person has no business on a sewage farm. On the other hand, paupers are sent to the large farms in troops of hundreds every spring and fall, and among these paupers there is always more or less sickness before being sent out; but we are told that no increase of sickness has ever followed their sojourn upon the farm and the inhalation of the tainted atmosphere, or the use of water from wells upon the premises. In weighing such statements, however, it must not be forgotten that the pauper stays on the ground but a short time and is then taken back to the almshouse, while the regular laborers and superintendents stay there permanently. There can be little doubt that the well-water on such a farm will, sooner or later, become tainted; but it is only after long experience with other than the most robust constitutions that a fair conclusion as to the consequence of the pollution of the atmosphere can be reached. In the cases of Dantzic and the English cities, we must not lose sight of the fact that the same are all located at or near the sea, where the great variations in temperature experienced in the interior of our own country are entirely unknown. What the results of such an intense heat as we had three days (July, 1887) ago would be on a large area heavily irrigated with foul sewage cannot be predicted, and must be determined by experience alone. The questions connected with sewage disposal are of vital importance to all engineers, and I hope that the other members will take them up and express their views fully. I can only say that so far as my observation has gone, I am still in a state of doubt. Agricultural experts of high standing express their doubts as to the pollution of the soil and the subsoil water, and sanitarians of unquestioned repute bear testimony to the pollution of the atmosphere. We are, however, now drawing inferences from conditions that are considerably different from those which obtain in our own land, and hence it is very desirable to have a record of such experiences as the members present who have constructed sewage-disposal works can give.

Without this knowledge of opinions and actual experiences, little can be accomplished. I doubt not but that Mr. Church can give some very interesting information in regard to his experience with sanitarians in relation to the contamination of the Croton water supply.

B. S. Church, M. Am. Soc. C. E.—I am not prepared at this moment to give statistics on this point. I hope to do so at a future time.

The Secretary.—I have been asked also to call the attention of the convention to the paper which has been recently issued in the transactions by our Chairman, Mr. McMath, a very interesting paper upon the determination of the size of sewers, giving results of experiments in

St. Louis with reference to the sewers in regard to the area which they drain.*

Mr. Robert Moore.—I will not discuss the subject which Mr. McMath has discussed so fully, but merely express the wish that other members of the Society who are in a position to observe and record facts in this connection will consider themselves under obligations to present them to the Society. Any one who has undertaken to ascertain what the sewers at any point actually do, the amount of rainfall which actually goes into them, will appreciate the extreme difficulty of the problem. And as there is no way of solving it except by observation, it is a duty of those in a position to make such observations to present them to the Society. I was in part instrumental in inducing Mr. McMath to present this able paper to the Society, and I hope that it may be an example to a great many others.

Mr. Kuichling.—I heartily second what has been said in regard to this matter; it is a duty which the members of the Society owe to each other in this work. Had I known of the existence of Mr. McMath's paper before, I would have been prepared to submit a few facts of some measurements made elsewhere. I hope that those members who have personal experience of this kind, will be generous enough to give us the benefit of it.

The Chairman, Mr. Robert E. McMath.—The suggestion that data and observations be sent to the Society is a good one, and I would say to the members that the facts may very properly be enlarged upon when writing, and they will go into the Transactions.

The question of sewage disposal as it has been discussed here I think may be broadened to advantage. We have been discussing sewage disposal by irrigation and, to some extent, by chemical precipitation. The question as it comes to most of us is not of how we are to use or destroy the sewage, but how we are to get rid of it without nuisance at the least cost. A common practice is to discharge it into a water-course or some body of water. Our western river towns do so, so far as they are sewered, and others will do so. Even now unbearable nuisances have resulted from the practice, and it pertains to engineers to collect and study facts, so as to fix the limits within which such a course is permissible.

It is commonly believed that a stream will purify itself while traversing an undetermined but moderate distance. Of course this must depend upon the proportion of sewage to the minimum volume of the stream, the character and material of the bed, the rate of flow and to mixture with other matter borne by the stream. We, at St. Louis, discharge our sewage into the Mississippi River, and we have supposed,

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* Determination of the Size of Sewers. Robert E. McMath, M. Am. Soc. C. E., Trans. Vol. XVI, p. 179, April, 1887.

judging from the results of chemical tests, that pollution practically disappears twelve miles below the last sewer. The ratio of sewage (the discharge of the sewers) to the river volume is small, about $\frac{1}{800}$ at lowest stage; but since the mixture is not complete $\frac{1}{200}$ is a fairer estimate of the actual dilution. The silt carried in the water is doubtless an active agent in the process of purification, but cannot well be estimated. The current at low stages is moderately strong, not far from three miles per hour. Under these conditions the receiving stream is not rendered offensive, except so far as a local discoloration immediately at the mouth of a sewer and detached pieces of floating offal may offend the eye and excite the imagination. Our sister city, Chicago, also discharges her sewage into a body of water which eventually passes into the DesPlaines and Illinois Rivers. The ratio of sewage to lake water is large ($\frac{1}{4}$), and the current in the canal about $1\frac{1}{2}$ miles per hour. At Joliet, 33 miles from the pumping stations at Bridgeport, the nuisance is intolerable at all times, and when the canal and rivers are frozen over the sewage pollution has been observed in disgusting proportion at Peoria, 159 miles from Bridgeport. At Peoria the ratio of sewage to water, river and lake could not have been greater than 1 to 10 at date of observation, January 5th, 1880.

The two cases I have cited present extremes and do little toward determining the very important question: How much dilution and opportunity for aeration must be given sewage in order that it may be disposed of in this manner without causing a nuisance? I think that we would do very well to give a little consideration to that subject. If any one has any facts in regard to the matter, here is a good time and place to present them.

Mr. Stearns.—I do not know that I can give any facts as to the amount of dilution required to prevent a nuisance, but can give some with reference to the pollution of a stream by the discharge of sewage. I refer particularly to the discharge of sewage from the cities of Lowell and Lawrence into the Merrimack River. The population of Lowell is 65 000; of Lawrence 40 000. The dry weather flow of the river is about two thousand four hundred cubic feet per second.

Last summer a series of chemical analyses were made, which showed considerable deterioration in the river water due to the discharge of sewage at Lowell; and the water still contained the bulk of the added impurities when it reached the intake of the Lawrence Water Works about 12 miles below.

A dozen years ago a similar series of analyses were made, and the chemist could not then detect any increase of pollution due to the sewage discharged from both cities.

I am told that at times in the winter, when the river is covered with ice, water from the river, standing in tanks in the houses at Lawrence emits a perceptible odor.

The sewage of Lowell is diluted some three hundred times by the dry weather flow of the river, and the effect upon the river water can be detected by chemical analysis, but it has not yet caused the abandonment of the river as a source of water supply. I think this can be called approximately the outside limit of noticeable contamination.

E. P. NORTH, M. Am. Soc. C. E.—How much of a fall is there between the two cities, and what is the character of the ledge that it flows over? I believe that has a very great influence, whether it is limestone or sandstone.

Mr. STEARNS.—Just below Lowell there are rapids where the water falls 11 feet. Below these rapids the effect of a dam at Lawrence is felt, and the river becomes a narrow mill-pond twenty feet or more deep. The ledge is neither limestone nor sandstone. I do not know its exact character.

It was not practicable to take suitable samples for analysis to determine the influence of these rapids, as they were located so near the City of Lowell, that the sewage did not get mingled with the water of the river until the falls were passed.

Mr. NORTH.—The soil is sandy?

Mr. STEARNS.—The banks are generally a fine sand or silt deposited by freshets.

The Chairman, Mr. MCMATH.—What Mr. Stearns has said about the pollution of streams reminds me of another feature presented at Chicago, which arises from the partial decomposition of the sewage in the Chicago River. The condition at Joliet is doubtless worse by far than it would be if the sewage was discharged into the canal fresh and there received a dilution to $\frac{1}{4}$. The question arises, is the distance to which pollution extends in the river, below Joliet increased or diminished by the partial decomposition effected in the Chicago River? It is proposed to enlarge the channel capacity of the canal and deliver the city's sewage into it in a fresh condition mixed with a larger volume of lake water than now. The towns along the Illinois River want to know whether the tendency will not be to extend the range of pollution—to diminish it in degree, but carry it farther? Also how much dilution they must insist upon as a condition to the privilege sought by Chicago? There is a dearth of facts bearing upon such questions.

Mr. STEARNS.—There is a current in all parts of the Merrimack River, even in the mill pond at Lawrence. I doubt if any odor could be noticed at the river even at an opening in the ice.

Mr. KUICHLING.—In regard to this matter of aeration of sewage, the question must be viewed with reference to the subsequent use of the water by which the sewage is aerated before the measure can be considered allowable. On this subject there are two extreme views, the one

being represented by Dr. Tidy, of England, who places considerable faith in the self-purification of streams, while the other is represented by Dr. Frankland, who says that there is no aeration sufficiently large, and no length of stream sufficiently great, to remove danger, if the water that has been polluted by sewage is used for domestic purposes. Between these two extremes, there is room for a vast amount of argument.

Last fall I attended the Annual Meeting of the American Public Health Association, at Toronto, where the question was raised whether the discharge of the raw sewage of that city into Lake Ontario, at a point several miles distant from the water-works' intake would be likely to result in the contamination of the city's water supply. Some claimed that an appreciable current flowed westerly up the lake, while others denied the existence of any such current, and insisted, that if there was any current at all, it was easterly, or down the lake. The question was to be voted upon by the tax-payers during the session of the Association, and the members were asked to express their views as to the expediency of the proposed scheme on the day before the vote was to take place, it being hoped that by a favorable expression on the part of the Association, the vote would be somewhat influenced in favor of the construction of the contemplated sewer. Among those present on that occasion, was the distinguished bacteriologist, Dr. George M. Sternberg, who, upon being urged to express an opinion, stated that it might fairly be said that there would be danger to the city's water supply if the sewage were discharged into Lake Ontario, as proposed. What the degree of danger was, he was not prepared to say; he would simply call attention to the fact that while researches on the development of germs had not been carried to any such extent as to warrant a sharp formulation of the problem, yet it was generally conceded that danger existed wherever sewage was thrown into a public water supply. Now, when we meet statements of this kind coming from men of profound learning and cosmopolitan fame, it is reasonable to presume that some danger, however small, does attend such conditions of sewage disposal; but in view of the large array of cases that might be cited where no evil results from the use of sewage-contaminated water have been detected in spite of the closest scrutiny, it behooves governments to conduct the most searching investigations as soon as possible, in order to arrive at definite conclusions upon these sanitary questions which cannot be acceptably solved by civil engineers in active life, and which frequently prevent the execution of much-needed improvements in large communities. To illustrate the opposite side of this question of stream-pollution, it may be mentioned that about twenty years ago, it was stoutly maintained that a dilution of one part of raw sewage in thirty parts of clean water, rendered the latter harmless; that limit was next stretched to one in sixty; it now stands one in three hundred, as advocated by the extreme school rep-

resenting the doctrine of the self-purification of streams by aeration and flow. These figures may not be exactly correct, as they are given from an indistinct recollection of data collected some time ago. Much has been written about the development of pathogenic germs in public water-supplies, but little appears to be yet known about their life-history in large bodies of substantially pure water in a state of rest; and it seems to me that on the answer to this question will a rational solution of this whole matter of sewage disposal greatly depend.

Mr. E. C. Clarke.—In considering what treatment is proper in any given case, it is well, first to decide how much it is necessary to accomplish. Whether it is sufficient simply to avoid causing a nuisance, or whether the greatest possible purity of effluent must be obtained to avoid contaminating a source of water supply. In the former case it usually will be enough to clarify the sewage by removing the suspended solid particles; in the latter case it is necessary also to treat the impurities in solution. This process requires comparatively large areas of of land; but sewage can be so clarified as to cause no offense to the senses by dosing small areas of land more heavily than will allow of purification, and also by the use of precipitants which affect but slightly the soluble impurities. I have seen cases in England where a clarified effluent nearly equaled in volume that of the stream into which it emptied, and yet, it was stated, that no nuisance resulted therefrom.

In this discussion it has been somewhat curious to note how difficult it has been to agree upon so simple a fact as, whether, or not, sewage farms commonly are nuisances. I have visited them and think they are not; Mr. Kuichling also has visited them and thinks they are. Certainly, where they have existed for some years people do not seem to be afraid of them. One sees blocks of newly built fine houses, which rent for from five hundred to a thousand dollars a year, standing within one hundred yards of sewage filtration areas. Adjoining the Beddington sewage farm at Croyden I saw a large school for girls, which was said to be full. Surely, parents would not send their girls there if it were exposed to offensive emanations.

It has been proved that sewage can be so purified by filtration as not to contaminate the soil water. In practice, however, owing to mismanagement or carelessness, there may be danger of such result. Still, liability to such danger is not a sufficient argument against the method. The problems in sewage disposal presented to most engineers are: how to avoid, or remedy, offensive and dangerous nuisances and direct pollutions of water supplies by crude sewage. These problems must be solved and remedies applied, even if the processes used do not give perfectly satisfactory results. Surely it is proper to mitigate a nuisance or substitute an occasional slight danger for a constant serious one.

Mr. Kuichling.—I fully agree with all that. I hold, however, that

it behooves an engineer who is called upon to undertake anything of this kind to know what is practicable before he broaches the subject of the construction of a large and expensive plan for sewerage. Any mistake he may make is likely to affect his career later. It is just this point that is up for consideration now, and what I have said was not meant to discourage the construction of works, but to call attention to the circumstance that there is possible danger, and to invite a careful scrutiny of the various conditions that now surround such projects.

It is essential to have these collateral branches of knowledge and science clearly brought out. A civil engineer has usually very little time for personal investigations in these new fields of science, but I think he needs to be fully cognizant of what he is doing, and to see where his mode of sewage disposal is going to lead him. This is especially true of engineers who live in the towns where they expect to spend their lives, or where they have been brought up and whose sewage disposal they are considering. The consulting engineer escapes censure in a great measure; he goes to a place, gives his advice, and then washes his hands of the whole transaction; but the man who stays on on the ground, the city engineer, is the one upon whom all subsequent trouble is going to fall, and therefore it is his business to know what the results will be. And if this fear of soil and water pollution be true, then before he recommends the expenditure of perhaps several millions of dollars for land for the purification of a city's sewage, he must know whether it is nevertheless the best thing that can be done under all of the circumstances attending the case. The eliciting of useful information should be the object of the present debate; and while not dissenting from most of what has heretofore been said by other speakers, it has been my purpose rather to call attention to such facts relating to the sewage question as have been reached from other directions, and to invite thereto careful consideration, for upon us the blame will come if we construct hastily.

With regard to the injection of air into sewage, I may remark that such processes have been tried by English chemists and experimenters without very favorable results. The introduction of air into slightly contaminated water produces some remarkable effects, the water being made sparkling and to some extent pure by this means; but in sewage its action seems to be too slow. The attempts to effect purification therewith were discussed by the English Rivers Pollution Commission, and I remember having read that the experiments were considered as not very successful.

A method was recently proposed of deodorizing the sewage of London, after previous partial clarification by the addition of oxygen in the form of a certain amount of permanganate of potash or soda to every gallon of the effluent. Very good results from that process appear to have been obtained for the conditions of London where they have

160 000 000 gallons of sewage to deal with per day, and where the effluent may be discharged into a large tidal river. The process consists in first treating the sewage with a little less than 4 grains of lime, 1 grain of sulphate of iron per gallon, after which the effluent is treated with from 1 to 1½ grains of permanganate of soda per gallon. These experiments were made on a large scale and are said to be quite successful. The effluent, however, does not reach the ground water, nor is the river water below London used for drinking purposes. The deodorization of sewage is one thing, while its purification, directly or indirectly, is another. Much hope is entertained of the future use and success of permanganate of soda in the treatment of sewage, as the cost of its manufacture has recently been reduced amazingly, so that its use is now possible in many of the English cities where the sewage must be clarified before being admitted into streams.

Mr. CHURCH.—How fully is that aeration carried out?

Mr. KUICHLING.—The suggestion of aerating the effluent of precipitating or filtering processes has not yet been tried on a large scale, so far as I know; but on small scales good results have been obtained by allowing the effluent to run slowly in very thin sheets over vertical wire cloth frames, thus exposing it to relatively long-continued action of the air. Similar results are also obtained by exposing the effluent to the air in the form of fine spray.

Mr. STEARNS.—As I remember the experiments made in England by Dibdin, some were carried on by forcing air into the bottom of tanks containing either crude sewage or the effluent from chemical precipitation; others by forcing the sewage into the air.

No provision was made for taking care of the odor blown out of the sewage, and it made a dreadful stink about the works.

The aeration was carried on for about 18 hours and it produced a considerable improvement in the character of the sewage, not enough, however, to compensate for the time expended and the nuisance created.

Mr. ROBERT MOORE.—I want to add a few words of testimony in the matter that Mr. Clarke has raised in regard to the facts at Pullman. I want to say that when I visited the Pullman sewage farm in November last there was no smell noticeable at all, except from a ditch in which the sewage stood stagnant at some distance from the filtration area, and that, if we had not known the contents of the fluid, I do not think we should have ever suspected what it was.

Mr. L. B. WARD.—In regard to the health of the men employed on these sewage farms, I had occasion to collect some data a year ago, and I found some valuable facts in a report made by a committee of the Royal Agricultural Society of England, who were investigating the best methods of sewage farming practiced in England, and the results obtained through a series of years on a number of model sewage farms entered in competition for the Society's prize. One point noticed was

the death rate of the persons employed on the farms. A table was given in which the death rate was shown to be much lower than for the average population. The death rate was very light, but I cannot just now give you the figures. The committee was composed of practical farmers and scientific men who would notice those points, and also the health of the working horses and cows which are kept in dairies at many of these places; this was noted as being extremely good. I suppose there is a difference in the condition of a farm that is well kept and one that is poorly kept, and this is probably, in some measure, the cause of the difference between the reports made by different persons.

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# AN INVESTIGATION

TO DETERMINE

# THE STRAINS IN A HOLLOW CAST-IRON DISK, COOLED FROM THE INTERIOR.*

By G. LEVERICH, M. Am. Soc. C. E.

The body of the Thompson 12-inch breech-loading rifle, fabricated at South Boston Foundry, is of gun-metal (refined cast-iron); the casting was hollow with closed breech; it was made with a sinking head, muzzle upward, and cooled upon the Rodman system, initial circumferential strains about the bore being induced. It weighed in the rough about 160 000 pounds. (For description and dimensions, see Report of Chief of Ordnance, United States Army, for 1876, page 96.)

The sinking head was separated from the muzzle of the piece by a cut about 1 inch wide; from this were taken two disks. The first disk, 13.7 inches internal and 44 inches external diameter and 3.68 inches thick, was tested to determine the initial tension of the casting and also the density and tenacity of the metal. For initial tension, a radial cut

* The measurements here recorded were taken December 10th, 1875, and the computations made in June following; this paper, as here presented, was written in November, 1881, and then laid aside. The rings and disk were a part of the Army Ordnance Exhibit at the Centennial Exposition in Philadelphia, 1876, and afterwards of the Army Ordnance Museum in Washington; however, without at either place any designation to show their origin or purpose.

was made in the disk with a planer tool and carefully extended downward, until the metal, still uncut, separated. The broken section was 13.5 inches long and 0.13 inches deep or 4.86 square inches. Comparing the differences in width of the opening thus made, it was deduced, quoting from the Report referred to above, page 100, that the "initial tension" was "18 500 pounds, or in a ratio of 0.533 to the absolute strength of the metal on the exterior." The specimens tested for density and tensile strength were then taken from this disk at points nearly equidistant from each other and numbered in order of their position from the outside towards the center. The results were as follows:

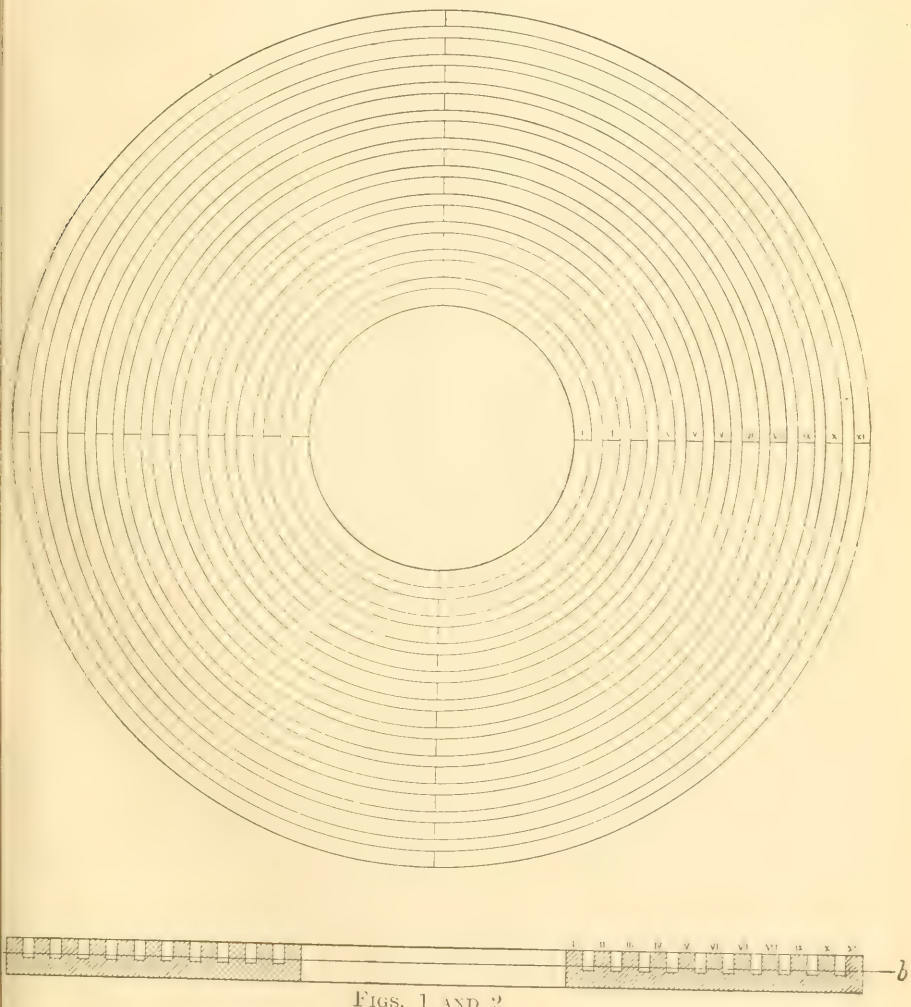
| Specimen | Location in Disk. | Density. | Tensile Strength, per Square Inch, Pounds. |
|---|---|---|---|
| 1 | Outside | 7.2729 | 34 529 |
| 2 | Two inches from middle | 7.2777 | 30 746 |
| 3 | Middle | 7 2 | 29 943 |
| 4 | Middle | 7.2789 | 29 710 |
| 5 | Middle | 7.2746 | 29 522 |
| 6 | Two inches within middle | 7.297 | 33 636 |
| 7 | Inside | 7.29 | 33 866 |
| | Means | 7.2858 | 31 707 |

A mean of strength of specimens Nos. 1, 5 and 7, being one each from the outside, middle and inside of the casting, say 32 500 pounds per square inch, more nearly represents the tensile strength of the metal than the mean given above.

The second disk, the subject of this examination, was separated from the first disk and from the sinking head by cuts about one inch wide. It was carefully finished over its entire surface to 13.8785 inches internal and 45.3666 inches external diameter and 2 inches thickness. Then, without removal from the lathe, two diametrical lines at right angles to each other were inscribed on one side of the disk, and ten grooves were turned in, 1.2 inches deep and from 0.573 to 0.606 inches wide, thus leaving eleven rings, from 0.895 to 0.9 inches wide, nearly equally spaced from the inner to the outer edges of the disk and attached to it, as shown by Figs. 1 and 2. These rings were numbered consecutively from the bore outward and then cut (on line $a$ $b$, Fig. 2) from the disk, so that the section of the rings was 0.9 inches square. The cut was so made that a small depth of the grooves remained on the disk, which was reduced to 0.9 inches thickness. After the rings were removed, the disk showed a

slight convexity on its face side. It will be seen that thus were provided for comparison, measures of the metal in the disk at eleven different points, equally spaced from the bore outward and of the metal at these points when detached and free from initial strain.

The measurements were made with a Brown & Sharpe's vernier rule, reading to thousands of an inch. The two diameters in each case were measured and their means taken; rings I, II and III were measured




FIGS. 1 AND 2.

direct; for the others the measure was set to the least diameter of the ring itself or of the corresponding groove on the disk and then applied to the other three diameters, as shown in Fig. 3; with one end of the measure at $a$, the extremity of the diameter $a\,c$ to be measured, an arc was struck cutting the circle at $b$ and $d$; the double line $b\,d$ was then measured, and from these two elements $a\,b$ and $b\,d$ the diameter $a\,c$ was computed by formula

$$\overline{ac} = \frac{\overline{ab}^2}{\sqrt{\overline{ab}^2 - \left(\frac{\overline{bd}}{2}\right)^2}}.$$

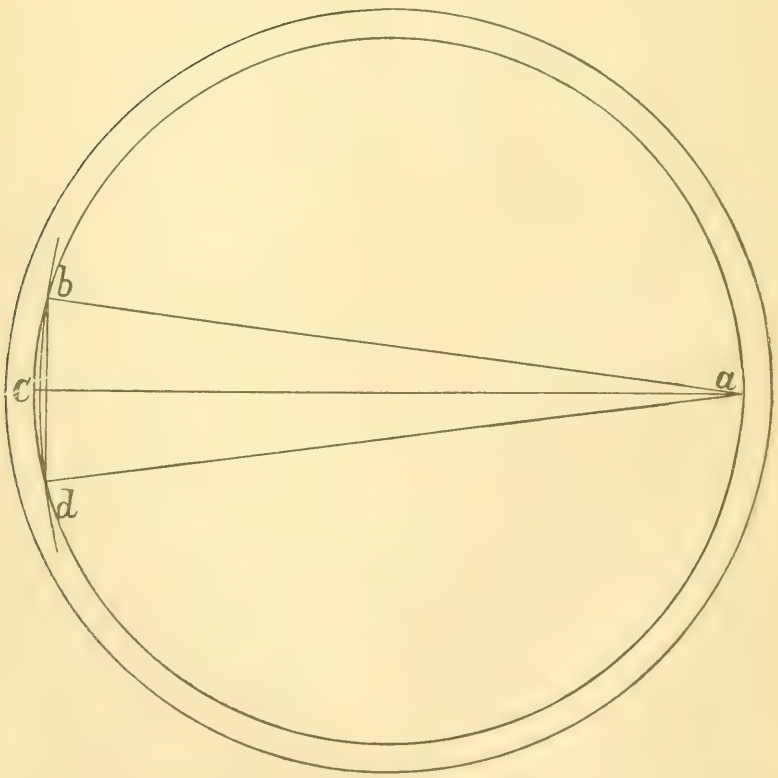



Fig. 3.

This method permitted great precision in measurement, with small possibility of error; since $b\ d$ could readily be taken to the nearest hundredth of an inch, a fractional error less than this would not materially affect the result, and the four diameters for each ring being measured with one length for $a\ b$, whatever small error occurred in taking this length was eliminated when the difference of mean diameters—the quantity sought was obtained. The results of these measurements are given in the following table:

| Rings. | Mean internal diameter on disk. | Widths along radius. | | Mean internal diameter of rings. | Differences in mean internal diameters. | Compressions or extensions per inch of circumference. | Strains per square inch necessary to produce these compressions or extensions. |
|---|---|---|---|---|---|---|---|
| | Inches. | Inches. | | Inches. | Inches. | Inches. | Pounds. |
| | | Ring. | Groove. | | | | |
| I..... | 13.8785 | 0.9 | ..... | 13.8965 | +0.018 | +0.00129529 | 24 000 |
| | | | 0.573 | | | | |
| II.... | 16.8245 | 0.9 | ..... | 16.838 | +0.0135 | +0.00080176 | 16 000 |
| | | | 0.606 | | | | |
| III... | 19.8365 | 0.899 | ..... | 19.843 | +0.0065 | +0.00032757 | 7 900 |
| | | | 0.6007 | | | | |
| IV.... | 22.836 | 0.898 | ..... | 24.843379 | +0.007379 | +0.00032302 | 7 600 |
| | | | 0.5845 | | | | |
| V..... | 25.801 | 0.9 | ..... | 25.808397 | +0.007397 | +0.00028661 | 7 000 |
| | | | 0.5925 | | | | |
| VI.... | 28.786 | 0.899 | ..... | 28.784995 | —0.001005 | —0.00003492 | 1 000 |
| | | | 0.5835 | | | | |
| VII.. | 31.751 | 0.896 | ..... | 31.747731 | —0.003269 | —0.00010297 | 3 200 |
| | | | 0.5825 | | | | |
| VIII . | 34.708 | 0.895 | ..... | 34.704503 | —0.003497 | —0.00009788 | 3 000 |
| | | | 0.5835 | | | | |
| IX.... | 37.665 | 0.899 | ..... | 37.662531 | —0.002469 | —0.00006556 | 2 300 |
| | | | 0.5765 | | | | |
| X..... | 40.616 | 0.898 | ..... | 40.605162 | —0.010838 | —0.00026692 | 7 400 |
| | | | 0.5825 | | | | |
| XI.... | 43.577 | 0.896 | ..... | 43.572613 | —0.004387 | —0.00010068 | 3 100 |

Fig. 4.

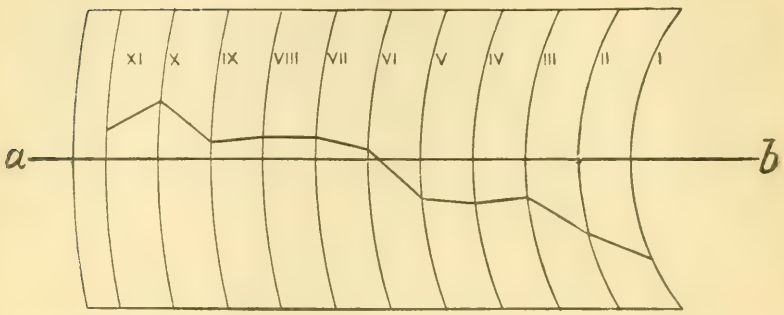



Fig. 4 is a diagram showing comparatively the compressions and extensions in the several rings placed as they were in the disk, and Fig. 5, another diagram showing comparatively these compressions and extensions per inch in circumference of the rings; $a\ b$ is the neutral line.

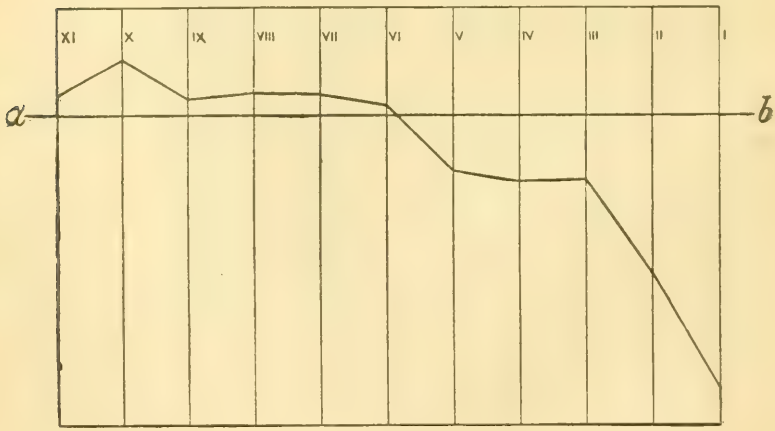



Fig. 5.

In "Reports of Experiments on the Properties of Metals for Cannon," etc., by Captain T. J. Rodman, 1861, page 211 and following, the relative compressions and extensions of cast-iron under strain and of a mean tensile strength of 24 500 pounds per square inch are given. Other and more complete data, resulting from similar tests of gun-metal

of greater tenacity, as now employed, not being at hand, it is assumed that the weights necessary to cause a given compression or extension in specimens of different tensile strengths vary as these strengths; the strains given in the last column of the table are so computed, for gun-metal, having a tensile strength of 32 500 pounds per square inch.

After the diameters of the rings were measured, a radial cut was made in the disk and continued downward until the metal parted; the broken section being 15.744 inches wide and 0.13 inches mean thickness, or 2.047 square inches—which, if the metal broke all at once and not continuously, and its tensile strength was 32 500 pounds per square inch, showed an initial strain of 66 530 pounds in the disk or of 73 920 pounds per inch in the length of the bore. The opening was 0.157 inches wide outside and 0.0555 inches wide inside; referring to the former, it was 0.00110154 inches per inch of outer circumference, which—per data for extension of cast-iron usually taken (Rodman's Report, cited above)—corresponds to between 14 000 and 15 000 pounds per square inch, tensile strain due to shrinkage, and taking data used in last column in the table—corresponds to between 18 000 and 19 000 pounds per square inch, tensile strain, either of which, it will be noted, is far in excess of that recorded in the Table.

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# DESCRIPTION OF THE WORK OF CONSTRUCTING A DAM ACROSS THE POTOMAC RIVER FOR INCREASING THE WATER SUPPLY OF WASHINGTON, D. C.

By SAMUEL H. CHITTENDEN, M. Am. Soc. C. E.

READ FEBRUARY 1ST, 1888.

The water supply of the City of Washington, D. C., comes from the Potomac River, and it is brought into the city through a closed conduit from above the Great Falls, a point about fifteen miles above the city. This conduit was built by the United States Government under the direction of General M. C. Meigs; the first appropriation was made in 1850, and the cost of the work of bringing the water into the city and building storage reservoirs was about three millions and a half of dollars; the conduit is circular in cross-section, 9 feet in diameter, and is built of brick and red sandstone from the Seneca Quarries, about 9 miles above the Great Falls; it passes over a rolling country, requiring high em-

banknents and heavy cuttings; at many points passing through several rock tunnels, and over four stone arch bridges, one, the celebrated Cabin John Bridge of 220 feet clear span; the conduit is well built, but not intended to be used under pressure. The dam at Great Falls that turns the water into the conduit has an elevation of 146 feet 9 inches above mean tide at the Navy Yard, Washington, which is the elevation of the center of the conduit at the upper end, and it has a fall of 9½ inches to the mile.

At a point about nine miles from the Great Falls, the conduit empties into a receiving and storage reservoir, made by building an earthern embankment across the Gunpowder Branch of the Potomac. From the lower end of the receiving reservoir the conduit extends about two miles to the distributing reservoir west of Georgetown; from this reservoir three mains of 12, 30 and 36 inches diameter respectively take the water to the streets of the city. The scarcity of water in the city is due to the small size of these mains and the want of a proper dam at the upper end of the conduit, and not to the size of the conduit or reservoirs.

Afterwards a connecting conduit was built around the receiving reservoir, so that the water supply could be taken directly from the Falls without passing through this reservoir, and so avoid possible contamination from surface water flowing into the Gunpowder Branch, which drains a thickly settled farming community.

As will be seen by an inspection of the accompanying map, the river at the upper end of the conduit is divided by Conns Island into two parts, called the Maryland, and Virginia Channels; much the larger part of the water passes down the Virginia Channel. When the conduit was first constructed, a dam of brush, clay and rip-rap stone was built across a part of the Maryland Channel to divert the water into the conduit; this proving entirely inadequate, the present masonry dam across the Maryland Channel to Conns Island was built, but for several years, in order to keep up the water supply in the low water season, it has been necessary to build temporary dams of brush and earth at the upper end of Conns Island to turn more water into the Maryland Channel.

In 1882, Congress provided for increasing the water supply by constructing a new reservoir east of Howard University and north of the city of a capacity of not less than three hundred million gallons, connecting this with the distributing reservoir west of Georgetown by a tunnel

about four miles long, seven and a half feet by eleven feet in cross-section. From this new reservoir a new system of larger mains was provided for, to reinforce the supply in the old system, and keep up the pressure; also to insure a full supply at all times at the upper end of the conduit, the Act ordered the extension of the masonry dam across Conns Island and the main channel to the Virginia shore, at an elevation of 148 feet above high water, and raising the Maryland Channel dam to the same height by a coping 15 inches thick. The work on this dam is the subject of the present paper.

The plans prepared by the engineer officers, and on which bids were received and contract awarded, provided for a masonry dam across Conns Island, a distance of about 700 feet, and from the island through shallow water, a distance of about 400 feet to Island Rock; also from the Virginia shore out to a point where 5 feet of water was reached; the section on Plate I shows the general features of this portion, the lower side, rock faced, coursed work, no stone less than 3 x 4 feet on the level, with 12-inch rise, and a coping 8 feet 3 inches long, across the dam, and 15 inches thick, no stone for coping to be less than 4 feet wide; two courses of ashlar were put under the coping on the up-stream side, the lower portion of the up-stream face, as well as the center of the wall, was of concrete; concrete was also used to level up for the first course on the face of the dam. The coping was secured to the wall by two bolts of inch and a half round iron, 30 inches long in each stone, while across each joint were set two clamps of 1½ x 1 inch iron, ends turned down 6 inches, and the whole clamp let into the stone. The construction of this masonry dam across the island, and through the shallow water, would leave a gap of about 350 feet of the deepest water; this section it was proposed to close by sinking cribs of sawed timber, afterwards filled with stone, when the bottom was 12 feet or more below the top of the coping; these cribs were to have a length of 24 feet up and down stream; the remainder were to be 16 feet; the other dimensions were to be varied as the bottom might require; the upper ends were to be set on the upper line of the dam, and the tops 3 feet below grade, to allow for a course of stone and coping to correspond with the other dam. After sinking the cribs and filling them with stone, the upper ends were to be covered with a double thickness of planking, and backed up with clay and rip-rap stone. An apron of oak timber was shown on top of the cribs below the coping; it was also provided that the end pens or bins

of the cribs should be filled with concrete, instead of loose stone, so that a good connection could be made between the crib work and masonry dams at each end.

Soon after the execution of the contract for the work at Great Falls, which included the crib dam in the deep water section, it was seen that this was a bad construction, and would not last long, the planking and clay above the cribs, and apron below the coping, would keep the water away from the timber, and allow the whole thing to rot down; the general plan of the crib work, and the conditions, seem to be very similar to those in the dam at Holyoke, Mass., which was repaired with great difficulty and expense, under the direction of Mr. Clemens Herschel, M. Am. Soc. C. E., and described by him in Transactions of the Society for August, 1886, No. 339, Vol. XV, p. 543.

The contractors called the attention of the engineers to this point, and after much discussion and estimates, it was decided that the appropriation was sufficient to build a masonry dam across the deep water section, and the contract was amended, requiring a masonry dam similar to the other. A cross-section is shown on Plate I. It was left to the contractors to decide how this should be accomplished, and the water kept out during construction.

The soundings showed the bed of the river to be rock, and the ledges on the Virginia side above the dam, and below it at the falls, as well as on the Maryland bank, evidently extended under the river. These ledges are composed of the Potomac blue gneiss of varying hardness; some layers soft and largely mixed with soapstone; all stand nearly vertical.

The records showed a long low water season in the summer and fall, but at all times liable to sudden rises from heavy rains, and the river then carried large quantities of heavy drift wood; the current at the site of the dam was rapid, requiring a good oarsman to stem it in a row-boat.

Several plans for excluding the water were considered. The plan adopted was, to first put in a dam of rip-rap stone from the Virginia bank to Island Rock, above the line of the permanent dam, afterwards filling in above the rip-rap with brush and clay to exclude the water. On the down stream side, an embankment of earth was carried out to the deep water, and then an ordinary box coffer dam with a clay filling as shown on Plate I was extended to Island Rock. After completion of the

masonry dam, the top of the rip-rap dam was pulled over against, it making the backing called for by the specifications.

The rip-rap stone was quarried from a bluff on the bank of the river about 400 feet above the Virginia end of the dam—clay of excellent quality, and in abundance, was found in a field 3 000 feet below the dam. A track was laid from the quarry to the dam, and the large stone loaded on small flat cars by horse power derricks, and drawn down to the end of the dam, where a gang of men was kept to unload cars, and keep up, and extend the track; at the same time the smaller stone and quarry chips were loaded by the use of wheelbarrows, on scows carrying about 15 tons each, and unloaded on the upper side of the rip-rap to close the larger holes before putting on the clay. The clay was hauled in carts and wagons to the shore at the end of the dam, and taken out in the scows and on the cars after the stone was in place; the top of the rip-rap was kept at an elevation of about 151, or 3 feet above the completed dam, a height supposed to be sufficient to keep out the ordinary rises of the river, but not the floods caused by heavy rains; the width on top was about 5 feet, as narrow as would carry a track of 3-foot gauge.

The arrangements for handling this material proved very unsatisfactory, and the stone could not be got in place fast enough; unloading the large stone from the cars all over the end, was slow work, and keeping up the track required a good deal of time and attention. We tried to push the rip-rap along by taking out stone on scows to the outer end of the dam; some stone was put in the bottom, ahead of the tracks in this manner, but the current was too swift, and it was difficult and dangerous getting the boats back.

The box coffer dam on the down-stream side was set up as fast as the rip-rap dam was extended, so as to break the current; the timber for posts and stringers and braces for this was cut on Conns Island, and roughly hewed; the general arrangement and sizes of the different parts are shown on Plate I. A small scow 7 feet wide was used for setting up the bents, the scow being moored to the last set of posts set up; its width gave the right distance out to the next set; soundings were taken at the location for each post, and the holes for the tie-rods bored so as to have the lower rod about 15 inches from the bottom of the river, the upper one the same distance below the low water surface of the river, and the center one one-third of the interval between the two others from the bottom rod; the stringers were cut about 10 feet long, and allowed to run past the posts; the sides were then planked in two layers, a 2-inch outside, and common 1-inch board inside, to cover the cracks. The clay was run out from the end of the dam in wheelbarrows, and after it reached the surface of the water, it was tamped with poles to consolidate it.

Afterwards, as the water was pumped down, braces were put in from the rip-rap dam to each post in the deeper water; through carelessness two of the posts used were of poplar, and the lower bolts, with ordinary cut-washers under the heads, were pulled through the posts, and allowed the bottom of the dam to bulge in at these points; additional braces were put in, and no serious trouble resulted.

Very heavy rains the middle of June, and again early in July, caused very high water in the river, carried away the track, tore down the upper part of the rip-rap, and broke off the outer end of the frame coffer, and caused at least six weeks' delay and extra work, so that it was late in September before we were ready to start pumping. A 6-inch discharge centrifugal pump, of Andrews' make, with an upright engine and boiler, also an 8-inch discharge Bush centrifugal, driven by a fifteen horse-power traction threshing engine were set up on the lower dam, and an attempt made to remove the water, but unsuccessfully; the water coming in through the seams in the vertical strata of the bed-rock, apparently very little hindered by our summer's work at damming; additional teams were put on hauling clay, and large quantities put in on both sides; on the lower side it was banked up against the side of the coffer, very nearly to the surface of the water; wherever a hole could be detected, bundles of straw were crowded in, and clay put on top; by this means, and the addition of another 8-inch pump, the water was lowered about 8 feet, and the work of building such portions of the deep water section as were accessible commenced. The season was now far advanced and closed, with about 200 feet of this section built, but leaving 150 feet of the deepest part untouched.

While the work of surrounding this section in the Virginia channel was going on, the section through Conns Island, about 700 feet long was completed, leaving a gap of about 400 feet between Conns Island and Island Rock, which it was decided to leave for the water to pass through, till the balance was completed. As soon as the rip-rap dam reached Island Rock, a trestle was built across the 400-foot open space, and a track carried across to transport the stone and material which came from the Maryland side of the river, and the work of building commenced at the Virginia end of the dam, so that when the working season closed, there remained to build 150 feet of the deep water section, about 400 feet between Conns Island and Island Rock, and the 15-inch coping to put on the old dam across the Maryland channel. The tracks, derricks and pumps were removed, and all work suspended for the winter. No particular damage was done by the winter's floods or ice, but the heavy drift brought down by the spring rise, tore down the upper part of the rip-rap in several places, carried out a section of the frame coffer and the trestle work connecting with Conns Island.

In April the work of repairing the damages was commenced; instead of rebuilding the trestle, cribs were sunk about 20 feet apart, and filled

with stone; at a point above the line of the dam, when the water-way was less, heavy stringers laid on these cribs carried the track; these cribs were intended to be used afterwards in the work of deflecting the water from the section below them.

The breaks in the dam were repaired; the 6-inch pump, and one of the 8-inch ones that was old and not very effective were discarded, and two new 8-inch Bush pumps put on, making three in all, and traction thresher engines hired to run them; these engines were found very convenient; a tramway of flattened logs was laid on top of the lower dam, and these engines would run out on it. In rainy weather, and when high water was feared, the pumps and engines could be removed to a place of safety in half an hour, and as quickly replaced; these three pumps were estimated, running at ordinary speed, to throw 10 000 gallons a minute. The leaks were not as bad as they had been the previous season, and the men were more skillful in finding and stopping them; some very large and troublesome ones were found and stopped, fully 40 feet from the outside of the dams.

The season was rainy, causing delay, but no serious damage was done, and this part was completed July 1st.

A few days after the completion of this deep water section, a rise in the river carried away the cribs that supported the track from Conns Island to Island Rock, and that were intended to be used as a support for a dam to turn the water over the completed portion, and out of the gap west of Conns Island.

New cribs were built and sunk, but with great difficulty, the water passing through the gap of 150 feet in width, and a depth of 5 feet, with great velocity. The cribs were built 8 feet wide, 25 feet long, and 9 feet high, of round poles notched at the corners, and secured by ¾-inch iron rods at each corner, holding the top and bottom together; a flooring of poles was put in to hold the stone used for sinking. The cribs were put together on a scow, and then the scow with its load let down by ropes from the shore as far as considered safe; wire rope guys were then fastened to the cribs and secured to trees on the island, and the cribs launched over the end of the scow, and allowed to settle down to position by letting out slack on the guys. It was, of course, impossible to move them up stream at all against such a current, and one or two that got too far down stream were abandoned. After the cribs were in place, they were filled with stone, from small scows let down from above along the wire guys; after they were filled, heavy stringers were placed against the upper ends of the cribs, and a planking of 1-inch boards put on; some care was taken to have those boards fitted to the inequalities of the bottom, but no close work was attempted; brush with heavy foliage, and bags of sedge grass, were then put in on the upper side, this of course did not make a tight dam, but it turned the water over the completed portion, and left about a foot of water

on the line of the dam; this was taken in sections of about a derrick setting each, and surrounded with small dams of sand bags and clay, the water thrown out and the dam built from each end of the gap. In this manner about 350 feet more of the dam was completed, except the coping on a portion, and preparations made for putting in the closure of 50 feet, when the weather put a stop to the season's work. Before the building had progressed far enough to raise the water, the place for the closure was selected, the bottom prepared, the concrete foundation and a timber frame work to hold the planking to throw the water through the gap in the coping put in; very little trouble was anticipated here, but the stone came slowly from the quarry, and the work was not pushed, in order to allow as much coping as possible to be set on the old dam; before the closing of this gap raised the water, winter weather commenced a month earlier than the year before.

The winter's floods tore away the upper part of the timber frame work around the closure, so that it was more difficult to get it tight when work was resumed in the spring, but the gap was closed the last of April.

Attention was then turned to the balance of the coping on the old dam; about 300 feet of this, being all the stone that was ready, was set before the last dam was put in in the Virginia channel, and while the water was below the top of the dam, the closing of the Virginia Channel gave a depth of not less than 15 inches of water on the old dam, when there was about 700 lineal feet of coping to set, but by slipping a derrick along on the coping as set, and using sand bags and clay to exclude the water, this stone was set, and the work completed August 1st, 1886.

## Materials.

The cut stone for masonry all came from the sandstone quarry owned by the Government at Seneca, 9 miles above Great Falls, and on the bank of the Chesapeake and Ohio Canal; this quarry was purchased by General Meigs for the purpose of obtaining the stone for the conduit; the stone is not as uniform in color as the stone known as Potomac red sandstone, but is a very durable and excellent building stone, and the quarry furnished all the coping required, about seven hundred pieces; the stone was cut at the quarry and taken down the canal on scows.

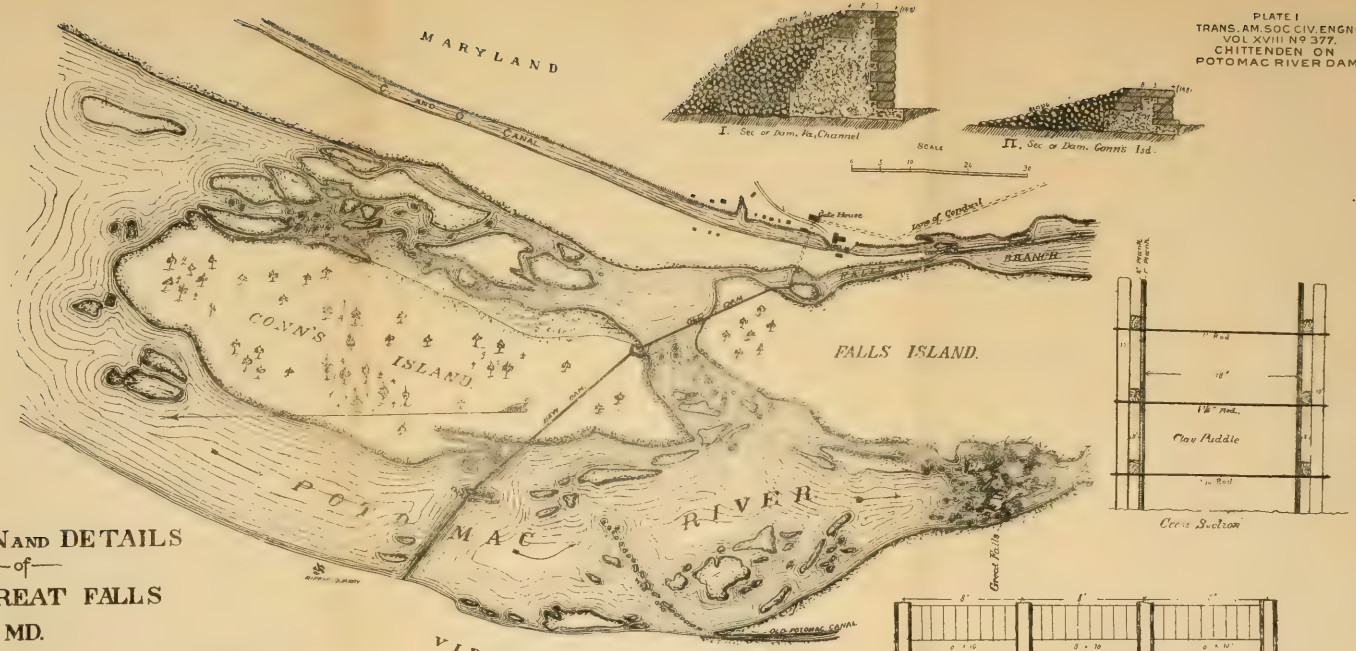
The stone for concrete was taken from the rip-rap quarry on the Virginia bank; a Blake crusher was set up between the quarry and dam, and the stone taken out in cars. The sand was obtained at first from the bars in the river, but this was found to be too dirty, and it was then brought up the canal from Washington. The cement used was mostly the so-called Cumberland cements "Round Top" and "Shepardstown," the canal being their usual route to market. "New York and Rosendale" was used in the channel section.

The stone, sand, cement and other material were landed on the canal bank, about 500 feet above the conduit, the stone being handled by a derrick worked by horse-power; a track was laid from this derrick to the bank of the river, and the stone, loaded on cars, was run down a scow built for the purpose with a track on deck; the scow was then poled across the Maryland channel and the cars drawn off by a horse on to a track that crossed Conns Island, close above the dam, and then across the trestle or cribwork to the track on the rip-rap dam in the Virginia channel.

I am sorry to say that I cannot give exact figures as to the quantity of material used and the cost of the auxiliary dam in the Virginia channel, but the men were moved from one point to another so much that the different parts could not well be separated.

I estimated that 7 500 cubic yards of rip-rap stone were used in the upper dam, and fully 10 000 yards of clay in all. The pumps were run continuously about one hundred and thirty days, not counting days when delayed by high water. The cost of pumping, including fuel, hire of engines and men was about $4 600, and the approximate cost of building and repairing the auxiliary dam and trestles and pumping for the Virginia channel work was $42 000.

PLATE I
TRANS. AM. SOC. CIV. ENGNS
VOL XVIII Nº 377.
CHITTENDEN ON
POTOMAC RIVER DAM







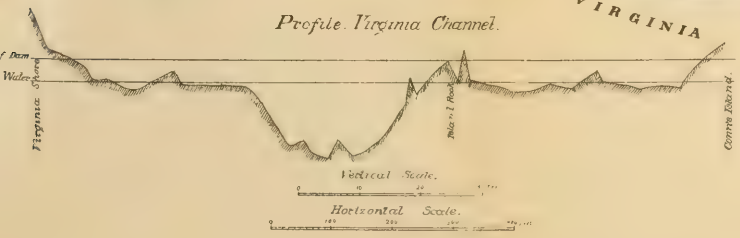


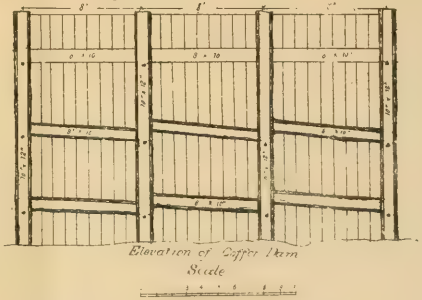







# LOCATION AND DETAILS —of— DAM AT GREAT FALLS MD.



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(Vol. XVIII.—February, 1888.)

# AN AUTOMATIC WASTE WEIR.

By A. D. FOOTE, M. Am. Soc. C. E.

READ JUNE 20TH, 1888.

In constructing canals across the drainage channels of an arid country, the engineer must provide for the sudden and ungovernable floods to which such countries are subject.

Slight though the rainfall may be in these regions, the sun-baked, verdureless hills present an impermeable surface, shedding water, for a time, like a roof, into the dry natural channels which thus suddenly become dangerous torrents. The most insignificant of these channels may, at intervals perhaps of years, become a river.

Canals crossing the drainage of such a country, must be carried either over or under all natural channels; or ways must be provided for the passage of such channels through the canals. The first two methods, if properly carried out, are excellent, but their enormous cost in most cases renders them impracticable. The third method is also often too expensive to be employed, especially where small channels are numerous. It is therefore only too common that canals are constructed without any provision for flood waters and in consequence are often washed out.

Mr. C. H. Tompkins, Jr., and myself have for some time been working over the problem of passing sudden flood waters through a canal at no great cost and without interfering greatly with its capacity.

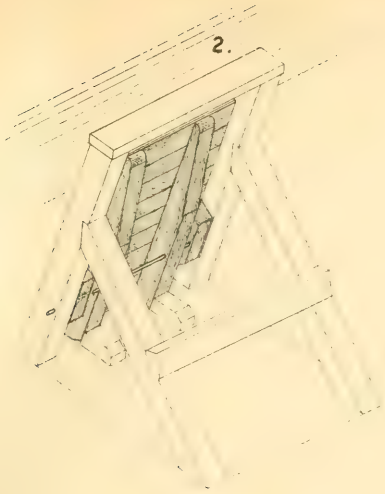
The accompanying drawing shows a form of gate which we have found perfectly to fulfill the above requirements so far as experiment shows. (Plate II.)

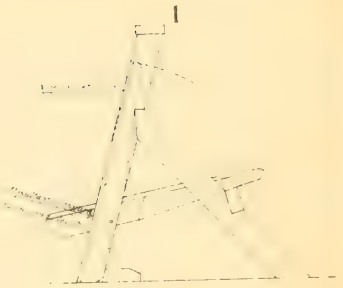
We have a working model set in an earth dam, in a small creek. It takes about ten minutes for the water to rise upon the closed gate to a height sufficient to open it. About two minutes are then required to lower the water to the point at which the gate closes again automatically. It is now over a month since the gate was put in operation, and in spite of poor workmanship in the model and the natural swelling and warping of wood, which, in so small a model, causes much more friction in proportion than in a large gate, the little affair has never failed to open at the proper time and has never failed to close again, except when some drift was caught in it. Had it ever failed to open, the water would have raised over the small earthen dam, and washed it away, as no other waste weir is provided.

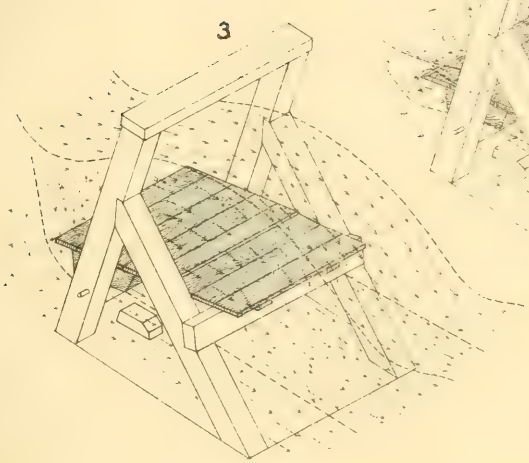
The drawing needs but little explanation. The gate is hung upon horizontal pivots, so placed that the water held in by the gate cannot rise above a certain point without raising the center of pressure above the pivot. When the center of pressure is raised high enough to overcome the friction and inertia of the gate, it opens; the top moving backward or down stream, until caught by a cross-piece, so placed that when the escaping water has been lowered to a certain point, the pressure, being removed from the upper portion of the gate, acts upon the lower portion only, and closes the gate.

In building these gates the pivot should be placed at the two-thirds point, measuring perpendicularly from the normal level of the full canal. The gate should be set at an angle from the perpendicular outward that will enable it to stand firmly without water against it. The distance from the normal level of the full canal surface to the top of the gate should be as great as the banks of the canal will allow. It will readily be seen that the greater this distance the greater will be the pressure of water for the purpose of overturning the gate, in case of any undue friction that may occur. The gate, when closed, should stand flush with the line of the side of the canal, so that there will be no opportunity for sediment to gather in front of the bottom of the gate.

In the drawing, the width of the gate is 6 feet, the depth of water at the normal level is 7 feet, and the height of the gate is 8 feet; con-

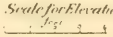


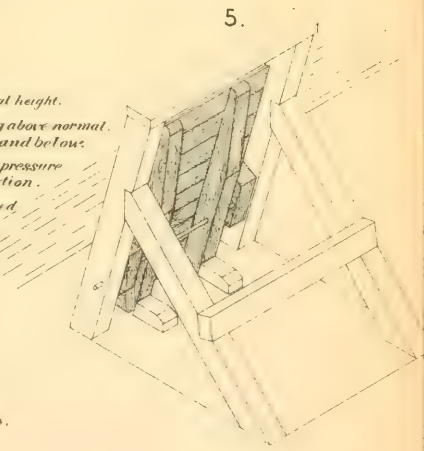



1. *End Elevation.*
2. *Gate closed, water level at normal height.*
3. *Gate opened by water level rising above normal. Water escapes both above and below.*
4. *Gate on point of being closed by pressure of water acting on lower portion.*
5. *Gate closed with water level reduced.*

*Scale for Elevation*




*Isometric scale*




# AUTOMATIC WASTE WEIR

DESIGNED MARCH—1888 BY A.D. FOOTE, G.H. TOMPKINS Jr.

E. March 30th 1888.

sequently when the water rises one foot above the normal level, it is exerting a pressure of 187 pounds upon the upper portion of the gate toward opening or overturning it. It will be a grievous fault in the construction of the gate if it fails to open under these conditions.

The angle at which the gate shall stop against the cross-piece, as shown in Figs. 3 and 4, is about 8 degrees from the horizontal. The amount of pressure exerted by the water upon the lower end of the gate to bring it back to its upright position, is not so easily calculated as the pressure that opens it. When the water is down, nearly to the level of the pivot of the gate, the rush of the current piles it up on the lower end of the gate so that the pressure exerted to close it is much greater than if the water were quiet. The amount of pressure will depend upon the angle at which the gate is held by the cross-piece.

Brush, or other *débris*, may clog the gate and prevent its shutting automatically, but this will entail no loss, except the waste of water while the gate is allowed to remain open. Where it is advisable to have the upper side of the canal kept uniform, ordinary barn-door gates, opening into the canal, can be used to allow the flood water to pass into and through the canal.

This weir can also be used to great advantage as an additional security for reservoirs. By placing them on a portion of the waste weir, they can be so arranged that a foot rise in the reservoir will quadruple, or more, if advisable, the capacity of the waste weir, by instantly adding several feet in depth to the overflow. They would save the expense and danger of an enormously long weir, and would give the desired capacity without lowering the ordinary height of the weir. By putting in a sufficient number, they would make it impossible for the water ever to rise to a dangerous height in the reservoir.

It also seems to me that they might be adapted for use in the automatic flushing of sewers, but in this kind of work I have very little experience. The gates could be so arranged as to require but a small amount of water to open them, and they undoubtedly will turn the water loose all at once. By properly arranging the flow above the gate they could be made to dump the water at desired intervals.

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(Vol. XVIII.—February, 1888.)

## NOTES ON THE CLASSIFICATION OF RAILROAD ACCOUNTS AND THE ANALYSIS OF RAILROAD RATES.

By Gratz Mordecai, Assoc. Am. Soc. C. E.

Read February 15th, 1888.

Something over a year ago I was requested by the United States Commissioner of Labor, Mr. Carroll D. Wright, to trace out what may be termed the development of the cost to the final consumer of some of the principal articles of domestic production and consumption—examining and analyzing each separate step, and then combining them all in a condensed summary; and though the investigation called mostly for statistical work, it may be that some of its phases will prove of interest.

Especially may this be the case in that part relating to the cost of transportation; and while I do not intend to give the final results in any case, it will do no harm to present my general methods with some special examples.

To be sure such an investigation must always be carried on from the one point of view of the final consumer and not from the many points of view of the individual operators ; it must be definite and limited in its scope ; it must start the initial raw material from a certain district or place at a definite date, and carry it by regular and representative methods through its whole course. For instance, iron ores mined in Michigan, carried in June by lake and rail to the furnaces and mills of the Mahoning Valley, and there other supplies added and work done and finally delivered as nails to a carpenter in Dayton, Ohio; or wool grown on a farm in Ohio, made into cloth in New England, into clothing in Chicago, and sold by a retail dealer at Minneapolis ; and in like manner each step which goes to make the cost of bread sold by a baker in Second avenue, New York City, and of beef sold by an East side butcher. It is evident that in order to make such investigations at all accurate in detail, or at all instructive in results, it is not only necessary to adopt a definite time and market price, representative points and a quick movement (storage and speculation are not considered), but that a certain general scheme of analysis should run through the whole, applicable alike to the work of a small farmer or a great railroad, of a wealthy merchant or a peddler. In fixing this general scheme of analysis I was greatly assisted by studying the working of a blast furnace, which is a concentrated operation, and yet contains the elements of any business and allows of a compact and simple method of keeping accounts. The value of the method I adopted comes from the almost mechanical consistency of its application.

It can be very safely assumed that all work contains three main elements of cost to the consumer :

1st. The cost of operating; 2d, the cost of soliciting; 3d, the cost of managing (which includes the profit of the operator) and under these heads it is not difficult to discern certain well-defined divisions. 1st, The cost of capital, such as rent and taxes; 2d, the cost of labor of all kinds; 3d, the cost of supplies consumed; 4th, the cost of repairs (in which labor and material should be always separated). The sum of these represents the total gross cost to the consumer, and by subtracting from this total (5th), the incidental receipts of the operator from waste and other sources, the market price or actual cost to the consumer is obtained. In some operations, as for instance, a dealer on an exchange, the work of operating is absent; but as a general thing, all these elements are present and also the five subdivisions under each head as is shown by the tables and examples.

Its application to railroad work is expressed in the general tabular form, Table No. 1 and special examples, Tables Nos. 2, 3 and 4. This general form applies both to the total yearly work (Table No. 2) and to special freight movement (Tables No. 3 and 4), but it is best to explain a few points before using it in the latter way.

The cost of capital, under the head of operating, in all the work of production and sale, is taken as the interest on the total cost or present value (in other words the rental, actual or deduced) of the work. In railroad work, however, it is only taken as the sum of all the fixed charges and no effort is made to fix the total cost or value of a railroad and equipment.

Hence in the first case the profit or loss under the head of managing work represents only the return for the work done, whilst in railroad work it represents only the return for the capital invested by the stockholders, and it is not considered that there is any return for the work done, and this appears for several reasons (being purely a transmitting work) to be a logical distinction, and in some cases doubtless a true expression.

To be sure, the work of managing depends upon the individual opinions and aims of the managers, their general and special policy, as well as the effects of supply and demand and of competition, and hence in analyzing any special market price at a given time, no attempt is made to separate the items of cost of this work of managing, nor any effort made to state the exact profit or loss on any particular movement. Still the difference between the market price and the sum of the cost of the commercial work of operating and soliciting always represents the cost of managing as a whole. Where the market price is greater than the total cost of the commercial work, the difference represents the net cost to the final consumer of the work of managing. Where the balance is the other way and the market price is less than the cost of the commercial work, the difference or loss of the managers represents the net receipts which the final consumer gets from the work of managing. Therefore, to obtain this lump cost of, or receipts from the work of managing in any given case, it is necessary to determine the cost of operating and soliciting, and the methods I have adopted in doing this in railroad work may be of interest. They have all been derived as correctly as possible from the published reports to stockholders and State officers. It may be well to state clearly that it is, and always will

be, impossible to obtain the exact cost even of the simple operating and soliciting work of moving any particular article at a given time between two given points by railroad, but I will proceed to give some special results, and in a general way state how they are obtained.

*First.*—The fixed charges actually paid chargeable to road freight work are all added up and divided by the total yearly ton mileage of the system, and this result multiplied by the number of miles the special article is moved over the system, gives the cost of capital chargeable to that movement. Car service and interest charges are charged against road work, but if there are any rentals or charges exclusively against terminal work, they are divided per ton handled, and added.

Then the cost of road labor, superintendence, train hands, watchmen, proportion of the agents, etc., is divided by the total ton mileage, and the result multiplied by the number of miles moved, and to the product is added the cost of terminal labor on the special article examined, derived largely from the excellent tables given by Mr. Octave Chanute, M. Am. Soc. C. E. The sum gives the total cost of labor chargeable to the special movement. Then the cost of fuel and supplies consumed, and of road and rolling stock and terminal repairs are treated in a similar way, and from the total sum is subtracted the total incidental receipts, also obtained by a similar method, resulting in the approximate net cost of operating that special movement. A similar method is adopted with the cost of soliciting work, and the total of operating and soliciting work subtracted from the special freight rate gives the total net result of the work of managing, chargeable to that special movement.

As many of these latter expenses of managing are of special application and indivisible per unit, no attempt is made to separate or define the items, and it is simply taken in all cases and in all work as the lump sum representing the cost of or receipts from the work of managing. It is a constant and interesting item in examining the cost of the work of a farmer or a manufacturer, of a retail dealer, or a railroad company. One of the specific examples here taken shows that the movement of a barrel of flour from Minneapolis to New York is done at less than the actual cost of the commercial work, and that the consumer receives thirteen cents from the managers of the railroad as their loss on the movement. But it must be noticed that this is less than the cost of the fixed charges chargeable to this work (twenty-eight cents), hence the difference (fifteen cents) is the amount earned from this movement towards paying the

fixed charges, and, therefore, this rate, fixed by supply and demand by competition and by public and corporate policy, is justified, especially when we consider the large yearly movement, and the resulting burden which would be thrown on other traffic if this movement were abandoned by the trunk line railroads, and the great public advantages arising therefrom ignored. Local business and more expensive goods which can bear higher rates, and are moved in smaller total quantities, do not separately pay as large an amount of fixed charges, but pay more of the cost of managing, including profit, which is large by unit of weight, though it may be small in total amount. It is thus seen that a large and long movement which actually does not pay the "cost of operating" may be more valuable to a railroad in helping it to earn its fixed charges than a considerable though short movement, yielding a large relative profit to the management.

This system of accounts is carried on uniformly through all the operations of commerce, resulting in the detailed analysis and development of the final cost to the consumer, and condensed summaries thereof.

In railroad work the basis of the system is the average cost of road work per ton mile, certain allowances being made for freight costing more or less than the average in some cases, and special additions being made for terminal and soliciting work, and the remainder representing the work of managing.

This plan is similar to the formulas prepared by Mr. Albert Fink, Past President Am. Soc. C. E., but I have tried to classify the items in order to separate clearly dissimilar and incongruous elements often found mixed in railroad reports. I have introduced the three main heads of operating, soliciting and managing, and have attempted to follow out under each the five sub-heads of capital, labor, supplies, repairs and incidental receipts, which last I have tried to express in each case in figures, for I have found that it is an important consideration in the clear understanding of commercial work.

# TABLE No. 1.

## General Analysis of the Cost to the final Consumers of the Movement of Freight on Railroads.

| Chief elements of cost to the final consumers. | Cost of Railroad's Work of | | | | Final cost of freight movement or railroad's gross freight receipts. | Per cent. of Final cost. |
|---|---|---|---|---|---|---|
| | Operating. | | Soliciting. | Managing. | | |
| | Road work. | Terminal work. | | | | |
| In analysis of any definite rate. | Divide by ton mileage. | Special. | Divide by ton mileage or special. | Not Specified. | | |
| *Cost of Capital*, paid to owners of money, property, franchises and rights. | (Proportion.) Interest paid on bonds. Rentals. Car Service. Fixed Charges. | Rentals. Car Service. Fixed Charges. | Rents of Offices, etc. | Taxes, etc. Stockholders' receipts, dividends, surplus, etc., credited to freight movement. (Proportion.) | Total cost of capital chargeable to freight. | Deduced. |
| *Cost of Labor*, paid to workmen. | Train superintendence, Watchmen, Clerks, etc. | Yard-house superintendence, etc. | Freight and soliciting agents, and Clerks, etc. | General Officers. General Clerks. Legal, etc. (Proportion.) | Total cost of labor Chargeable to freight. | Deduced. |
| *Cost of Supplies*, paid to producers and merchants. | Fuel, oil, water, waste, etc. | Fuel, oil, water, waste, etc. | Fuel, Office supplies. | Investments. Banking. Money in use, etc. (Proportion.) | Total cost of supplies chargeable to freight. | Deduced. |
| *Cost of Repairs to*, paid to workmen and merchants. | Plant. (Labor and material separate.) | Plant. | Offices, etc. | Insurance, Losses, Discounts, etc. (Proportion.) | Total cost of Repairs chargeable to freight. | Deduced. |
| Gross Cost. | Total. | Total. | Total. | Total. | Total Gross. | Deduc'd |
| Less incidental receipts of railroads, etc. | Rents Supplies Waste Use of road. | received. sold. sold. Use of Termini. | From rents, waste, etc. | From stockholders' interest on investments, etc; also from stockholders' losses; final loss | Deduct incidental receipts chargeable to freight. | Deduced. |
| Net cost to final consumer. | Net Cost. | | Net Cost. | Net Cost. | Final cost or railroad's fr't earnings, *i. e.*, gross receipts from freight. | 100.0 |
| Per cent. of final. | Deduced. | | Deduced. | Deduced. | 100.0 | |

Note.—All transfer work in road-work. Termini are where a station yard engine is used.

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## TABLE No. 2.

Analysis of the cost to the final consumers—being Railroad's gross Freight Earnings—due to the movement of freight in the year 1886 on the main line and branches of a Trunk-line Railroad having a terminus at New York City (figures deduced from annual report).

Total miles of road operated.. 1 441 miles.
" freight moved..... 12 718 101 tons.
" freight mileage.....2 414 266 463 ton miles.

| Elements of Cost. | Cost of Railroad's Work of | | | | Total Cost. | Per Cent. of Final Cost. | |
|---|---|---|---|---|---|---|---|
| | Operating. | | | | | | |
| | Road. | Termini. | Soliciting. | Managing. | | | |
| Cost of Capital..... | 5 082 840 | 54 240 | 100 000 | *3 408 128 | 8 645 208 | 47 | (—9 ... Nett) |
| " Labor ..... | 2 792 547 | 2 842 732 | 364 972 | 236 140 | 6 236 391 | 34 | |
| " Supplies..... | 1 220 156 | 109 256 | 5 000 | 19 447 | 1 353 859 | 7.5 | |
| " Repairs..... | 3 510 267 | 200 000 | ..... | 156 807 | 3 867 074 | 20.5 | About labor, " " mat'l. |
| Total Cost gross..... | 12 605 810 | 3 206 228 | 469 972 | 3 820 522 | 20 102 532 | 109.0 | |
| Less incidental receipts.. | 1 000 000 | | ..... | 626 000 | 1 626 000 | A 9.0 | Part of dividends hence are taken from capital cost — above A. |
| Net Cost..... | 14 812 038 | | 469 972 | 3 194 522 | 18 476 532 | 100.0 | |
| Per Cent of Final Cost... | 80.0 | | 2.5 | 17.5 | 100.0 | | |

NOTE.—All general items not specially allotted in the report to either passenger or freight business (such as interest, rents, dividends, etc., all paid and received) are here allotted to freight movement in the proportion that the earnings from freight movement bear to the total (operating) earnings.

*The actual dividends and surplus for the year chargeable to profit on freight movement amounted to $866 135. The remainder of this charge comes from taxes ($916 877) and incidental receipts—rents, etc., $1 626 000 allottable to freight movement, and this last item forms the chief part of the yearly dividends and surplus which really arise more from incidental receipts, rents, mail, express, etc., than from profits on passenger and freight movement.

## TABLE No. 3.

Analysis of the cost—to the final consumers—of moving a barrel of flour (215 pounds gross) by rail from a mill in Minneapolis to a freight pier in New York City over three independent railroads having a through freight rate over the route, which is 1 400 miles long : 420 miles over the first, 540 miles over the second and 440 miles over the third or Eastern.

### Cost of Railroads' Operating (variable) per Barrel, October, 1887.

| | | |
|---|---|---|
| Cost of Capital, interest, fixed charges, rents, etc..... | 0.28 | |
| " Labor, on roads and at terminal points..... | 0.18 | |
| " Supplies—fuel, etc ..... | 0.09 | |
| " Repairs, to plant, labor and material..... | 0.25 | |
| Total cost of operating..... | 0.80 | |
| Less incidental receipts..... | 0.03 | |
| Net cost of operating..... | | 0.77 |

### Cost of Railroads' Soliciting (variable) per Barrel.

| | | |
|---|---|---|
| Cost of capital, 0.00; labor, 0.01; supplies, 0.001; repairs, 0.001. | | 0.01 |
| | | 0.78 |

### Receipts from Railroads' Managing (Items indivisible).

| | | |
|---|---|---|
| Cost of Capital, taxes, etc..... | | |
| " Labor, general officers, legal, etc ..... | | |
| " Supplies, banking, investments, etc..... | | |
| " Repairs, insurance, losses, etc..... | | —0.13 |
| Total cost of managing. | | |
| Less receipts from incidental sources. | | |
| Net receipts from managing, including, but not stating, railroads' net loss on this movement ..... | —0.13... | |
| Final cost to the consumer or through freight rate per barrel of flour—Minneapolis to New York—October, 1887.... | | 0.65 |
| (This is a large total movement.) | | |

## TABLE No. 4.

Analysis of the cost to the final consumer of moving a case of dry goods (220 pounds gross) between two local stations 60 miles apart on one of the railroads referred to on Table No. 3.

### Cost of Railroad's Operating (variable) per Case.

| | | |
|---|---|---|
| Cost of Capital, interest, fixed charges, etc | 0.01 | |
| " Labor—on road and at stations | 0.02 | |
| " Supplies, fuel, etc | 0.01 | |
| " Repairs to plant (labor and material) | 0.02 | |
| Total cost of operating | 0.06 | |
| Less incidental receipts | 0.00+ | |
| Net cost of operating | | 0.06— |

### Cost of Railroad's Soliciting (variable).

Cost of Capital. Labor, 00+ Supplies. Repairs. 0.00+

### Cost of Railroad's Managing (Items indivisible).

| | | |
|---|---|---|
| Cost of Capital, taxes, etc | | |
| " labor, general officers, legal, etc | | |
| " supplies, banking, etc | | |
| " repairs, insurance, losses, etc | | |
| Total cost of managing | | 0.27 |
| Less receipts from investments, incidental, etc | | |
| Net cost of managing, including, but not stating, railroads' profit on movement | 0.27 | |
| Final cost to consumer or local freight rate for 60 miles, a general rate between several local stations, 15 cents per 100 pound (small total movement) | | 0.33 |

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(Vol. XVIII.—March, 1888.)

# THE CABLE RAILWAY
ON THE
# NEW YORK AND BROOKLYN BRIDGE.

By G. LEVERICH, M. Am. Soc. C. E.*

1st.—The New York and Brooklyn Bridge, more commonly known as the East River Bridge, is the suspension bridge which spans the East River and connects the cities of New York and Brooklyn. The structure proper extends from the easterly side of Chatham street (recently re-named Park Row) New York, to the westerly side of Sands street, Brooklyn, being on the centre line, from end to end 6 017.33 feet in length. Extensions for switching and storage of cars reach, one in New York over Chatham street, 109.88 feet, and one in Brooklyn over Sands and High streets, 389.22 feet.

## I.—DESCRIPTION.

2d.—THE RAILWAY.—The railway proper is from New York Station on the easterly side of Chatham street, to Brooklyn Station on the westerly side of Sands street; passengers being received and discharged only at these points. The railway is double-tracked, of the standard gauge, 4 feet 8½ inches, and laid with steel rails weighing 52 pounds to

* This Paper in an incomplete form, was read at the Annual Convention, July 6, 1887; it is now brought down to May 1, 1888.

the yard; the grade ranges, as shown by profile,* Plate XXVI, from nearly level, to over 3½ per cent.; the summit in the center of the suspended span, being at a mean height above the track in New York Station of 81.3 feet, and in Brooklyn Station of 56.9 feet. The length of cable within the rails, between the outgoing and incoming sheaves, and therefore available for train service, on the northerly track is 5 446.7 feet, and on the southerly track 5 441.4 feet; a total of $2\frac{1}{16}$ miles.†

3d.—Cable Driving Plant.—The cable is driven continuously in one direction by either of two stationary steam engines, placed underneath the Railway in the Brooklyn Approach, a short distance westerly of Brooklyn Station; the cars are attached to the cable by a roller grip, one on each car, and are run singly or in trains, as the traffic requires; they are switched at the stations from one main track to the other by locomotives, which also are used to haul the trains in the night time when the travel is light; or when from any cause, the cable is temporarily stopped. The cable driving plant consists of steam boilers and engines, winding drums, tension cars, guide and deflection sheaves, bearing and tilting pulleys, and their several attachments. ‡

4th.—The Boilers.—There are six water tube steam boilers of a well-known type; they are set in pairs, and may be operated singly or together; each has 54 water tubes, 4 inches in diameter and 18 feet long, also a cylindrical steam drum 3 feet in diameter running the full length of the boiler, and is rated at 104 horse-power; the grates are 3 feet 10 inches wide and 7 feet long; they have revolving self-stoking grate bars. The boiler house is a detached brick building; the chimney is of brick, double walled up to 33 feet from the top; its base is 15

* This is the construction profile; the grades shown for the suspended structure being those which were intended it should have at a temperature of 90° Fahr. The superstructure rises and falls inversely with the temperature and the grades on it vary considerable from those shown.

† During the design, construction and operation of this Railway, the engineers principally in charge were: Washington A. Roebling, Chief Engineer to July 1, 1883, who was then succeeded by Charles C. Martin, formerly Principal Assistant Engineer, since Chief Engineer and Superintendent; William H. Paine, Assistant Engineer to January 1, 1886, and now Consulting Engineer; and Samuel R. Probasco, now First Assistant Engineer. The writer was not engaged in this department until October 4, 1883.

‡ Letters Patent of the United States, upon portions of this plant, have been granted to William H. Paine, as follows:

173 329—Device for connecting Cars with moving Ropes; February 8, 1876.
296 602—Cable Railway Appliances; April 8, 1884.
296 603—Auxiliary Switching Apparatus for Cable Railways; April 8, 1884.
296 604—Gripping and Brake Mechanism for Cable Railways; April 8, 1884.
296 605—Roller Grip for Cable Railways; April 8, 1884.
296 606—Automatic Connector and Disconnector for Grips of Cable Railways; April 8, 1884.
331 237—Cable Supporting Sheaves for Cable Railways; November 24, 1885.
331 238—Hand Mechanism for Operating Grippers for Cable Railways; November 24, 1885.
331 239—Rope Driving Machinery; November 24, 1885.
371 095—Gripper for Cable Railways; October 4, 1887.

feet 4 inches square, and its height from foundation to top, 139 feet 10 inches; the flue is 5 feet 3 inches square at the base, and 5 feet 6 inches square at the top; its height is 129 feet 4 inches. A platform elevator lifts the ashes from the boiler house floor, about 15 feet up to the level of the adjacent sidewalk; it is operated by a steam winding engine, with cylinder 6 inches in diameter and 7 inches stroke. The chimney drafts are controlled by an automatic damper regulator, whereby the boiler pressure, under all the changing loads imposed on the engines, is kept close to the mean limit, or about 76 pounds. The feed water is supplied to the boilers by a direct acting steam pump with steam cylinder 10 inches and pump cylinder 6 inches in diameter; the stroke is 12 inches. The exhaust steam passes through a vertical tubular feed water heater, 3 feet 4 inches in diameter and 11 feet high. Besides furnishing steam for the engines of the cable driving plant, these boilers supply one or more of three electro-lighting engines, each of about 50 horse-power, and one workshop engine of about 20 horse-power; also in cold weather for heating Brooklyn Station, the office building and the workshops.

5th.—The Engines.—For the cable driving plant there are two horizontal steam engines; the cylinders are 26 inches in diameter and the stroke 48 inches; the fly-wheels are 18 feet in diameter and weigh 30 000 pounds. These engines have a specially devised automatic cut-off valve gear; they are connected to the outer ends of the main or drum shaft and drive it by jaw clutches, but one engine being operated at a time. At mean speed they make 57 revolutions, or their pistons move 456 feet per minute. The position of the engines, drums, the Brooklyn tension car and the Brooklyn sheaves, is shown in Plates III and IV.

6th.—The Drums.—There are two large drums, 12 feet in diameter with 26 inches face, and one small drum, 5 feet in diameter, with 31½ inches face. There are four semi-circular grooves, originally ¾ inch deep, in each of the large drums; the shafts are placed in vertical planes 17 feet apart, and are inclined in different directions, 1 in 128 from the horizontal, so that the grooves at the bottom of the drums, are opposite each other and at the top, the second, third and fourth grooves of one or the driving drum are opposite respectively the first, second and third grooves of the other or driven drum; thereby the lines of cable as it is wound around the two drums, pass fairly from one set of grooves to the other. The small drum is placed midway between the large drums, and fills nearly or quite the entire space, except opposite the grooves, where its face is cut away; it runs loose on the main shaft. On one side of the small drum and close to it, is keyed to this shaft a pinion with 35 teeth and pitch circle 5 feet in diameter, which gears into a wheel keyed on the shaft of and bolted to the driving drum; this wheel has 84 teeth and pitch circle 12 feet in diameter; the pitch of the teeth is 5.39 inches and their face length 12 inches. At mean speed the large drums revolve 23¾ times per minute, whereby the mean speed of the cable would be 895.35

feet per minute or 10.17 miles per hour, were the grooves unworn and there was no slipping on the drums; the mean speed of the cable is generally taken at 880 feet per minute or 10 miles per hour. The drums and their bed plate are shown in Plates III–V; the gear-wheel and pinion being omitted from all but the elevation, Plate III.

7th.—The Cable.—The cable is made of crucible steel; it is about 11 500 feet long; when new it was $1\frac{1}{2}$ inches in diameter, and weighed $3\frac{1}{2}$ pounds to the foot length. It contains 114 wires, each nearly $\frac{1}{10}$ inch in diameter, laid in six strands around a central strand of hemp. Beginning at the point where the cable first reaches the drums, its course about them is: down, one fourth way around the driving drum, half way around each drum successively three times, and up one fourth way around the driven drum; from the drums it passes over a guide sheave, around the sheave of the Brooklyn tension car, under another guide sheave, up through the arch of Brooklyn Approach and over the outgoing sheave near Brooklyn Station to the northerly track of the Railway; along this track to the incoming sheave in New York Station; thence down under the Railway, around this and two other sheaves and under the footway to the New York tension car; around the sheave of this car, over the outgoing sheave in New York Station, up to the southerly track of the Railway; thence along this track to the incoming sheave near Brooklyn Station, over this sheave and down through the arch of Brooklyn Approach to point of starting.

8th.—The Tension Cars.—To prevent the cable, under whatever traction resistance it has to overcome, from slipping on the drums, as well as to take up whatever elongation there may be in the cable at the rear of trains from Brooklyn Station, a certain stress must be maintained in the cable as it leaves the drums, and this is done by the Brooklyn tension car. To take up the elongation which, more or less, runs before trains from Brooklyn after they pass the summit, as well as that which may follow trains from New York until they reach the summit, the New York tension car is provided. Each of these cars also act when the length of cable is increased or lessened by changes in atmospheric temperature. The tension cars are shown in Plates IV and IX; each has a cast iron frame, which rests on four flanged wheels and carries a sheave; that in Brooklyn being vertical and running in two pillow blocks, and that in New York being inclined and running in one long journal box. The cars traverse an ordinary railway track of 3 feet gauge, on a grade of 20 per cent. in Brooklyn and of 46 per cent. in New York. To prevent the New York tension car from being overturned by the side strain to which it is subjected, there is a third rail, close underneath the sheave, above and parallel to the main track, traversed by a pair of small guide wheels, attached to the tension car frame; this rail and the guide wheels are not shown in the Plates. The cars are weighted, and to relieve that in Brooklyn from an undue load on its wheels, an additional

weight was recently attached by means of a wire rope and two pulleys, so as to oppose directly the forward movement of the car. The initial stress on each line of cable, running to and from the car, thereby caused is in Brooklyn about 1 800 pounds, and in New York about 1 500 pounds. At times an excess of train loads running down grade may increase the back haul on the tension cars much above these limits. To prevent too great movement then, a barrier is kept before each car against which it will bring up; also on the Brooklyn tension car, as shown in Plate IV, a weighted brake is hung over each wheel, so as to yield readily when the car moves down grade and to resist when the movement is in the contrary direction.

9th.—The Sheaves.—The sheaves, as first used, are shown in Plate X. They were cast in one piece with hubs split into three parts; a flat wrought iron band was shrunk on each end of the hub, which was then bored, the shaft inserted and keyed fast. The rim including the groove, was turned, and the cable ran in contact with the metal surface. Some of the sheaves were replaced by others made as shown in Plate XI. These were in two parts, the rim and the arms; the bearing surfaces were finished and the parts bolted together by turned bolts driven into reamed holes; the groove for the cable was solid, however, as before. The two sheaves shown in Plates IX and XVII, as first made were similar to those shown in Plate X, except that the rim was in parts bolted together; they enclosed in the groove, which was dovetailed, a packing of seasoned hickory blocks, boiled in linseed oil, placed with fibers radial and then turned out to receive the cable. For these packed sheaves were substituted others made as shown in Plate XII, differing from that shown in Plate XI, in having the rim divided as just described, and packed with leather and india rubber belting, placed radially in the proportion of ten thicknesses of leather to one of india rubber. As shown in the Plates, the sheaves generally have a shaft, running at each end in a pillow block, and are supported by cast iron frames bolted to the masonry; the exceptions are; the New York tension car sheave as already noted, and the horizontal sheave under the footway in New York Station, which runs loose on a fixed shaft. Some of these journals are 3 and others 4 inches in diameter; those which run in pillow blocks are 6 inches long. The pillow blocks are shown in Plates XIII and XIV; those first used were in two parts and babbitted; some of these were replaced by other pillow blocks, having brass bearings, cut into four parts and arranged to adjust for wear in two directions.

10th.—The Pulleys.—The cable between the rails, is supported by fixed and tilting pulleys, shown in Plates XV and XVI; in each the groove for the cable is packed with leather and india rubber belting placed radially; a larger part being india rubber. The pulleys are cast in one piece, and in the solid groove the packing is laid piece by piece as closely together as may be; the small spaces left are filled and the

outer grooved surface coated with coaltar pitch, applied hot. Other packings, as of hemp, and of india rubber in one mass filling the groove and vulcanized in place, have been tried, but were unsatisfactory. The fixed pulleys are on a steel shaft which runs in two bearings; the journals are 1 inch in diameter and $1\frac{3}{4}$ inches long; the journal boxes are in two parts, the upper or cap being hinged to the other and fastened by a self acting latch, recently attached and not shown in the Plate; the bearings are of babbitt metal and do not fill the entire length of the box; the space left forms a reservoir for oil, which is kept in by a circular fillet fitted into a groove around the shaft near the inner end of the journal. The pulley frames are bolted to the cross ties of the track, the fixed pulleys being placed generally 30 feet apart; their position on the suspended structure is shown in Plate VII, and in relation to the cross ties and rails, it elsewhere is substantially the same.

Generally the cable is 3 inches above the rails; at the two places where the grips are attached, it must be raised from $4\frac{1}{2}$ to 8 inches higher; for which purpose the tilting pulleys, put 12 feet apart in New York Station and 6 feet apart near Brooklyn Station, in number sufficient to serve the longest train run, are employed. These pulleys run loose on one end of a horizontal pin, which is at the free end of a counter balanced lever; on the other end of this pin is an idle flat faced wheel, against which the inverted bent rail, forming a part of the grip mechanism now used, shown in Plate XXI, and to be described, bears when the grip is to take hold of the cable. The lever is pivoted at the fixed end and is placed so that the pulley is on the same side as where the cable runs. The tilting pulley shown in Plate XVI is as it was first made; the lever was weighted so as normally to hold the cable somewhat higher than its place in the grip and as the cars passed over, the lever was depressed by the inverted rail, leaving the cable suspended. Now, the shafts to which the levers are attached are extended to one side of the track, and by cranks and a long jointed connecting rod, with a coiled spring interposed at each crank, all the pulleys in one place are united together, and by other cranks and rods, a workman detailed for the purpose, from one point, elevates the pulleys and the part of the cable which is supported by them and underneath an outgoing train, until the grips take hold and then he allows the pulleys to fall back to their lower position. Recently the weights have been replaced, each by a coiled steel spring, so attached to the lever as to nearly balance it and its parts during the entire movement up and down.* The hubs of the tilting pulleys are made hollow; the enclosed space serves as an oil reservoir for lubrication.

11th.—The Cars.—When the Railway was first operated, it had 24 passenger cars; one half being 36 feet 4 inches long, weighing $8\frac{1}{2}$ tons, and one half 48 feet long, weighing 10 tons each, with doors at the ends

* Letters Patent of the United States, upon this improvement, have been granted to Origen C. Crane, as follows:

383 703—Cable Supporting Sheave for Cable Railways; May 29, 1888.

only. Afterwards the shorter cars were discarded, side doors were introduced, and from time to time as required, other cars, stronger and heavier, were procured, until now there are 44 in use. These are all essentially alike; one of the last purchase, partly shown in Plate XXIV, may represent the whole: it is 48 feet 10 inches long between draw bar or coupler pins, and 39 feet 6 inches from end to end of body, 9 feet 7 inches wide out to out, and 13 feet inches 8 high from the track to uppermost point; with a 4 wheeled truck at each end, 32 feet 5 inches apart from center to center of truck pins, and axles 5 feet apart. The wheels are of paper, steel tired; they are 30 inches in diameter, with treads 4 inches wide. The unloaded car weighs 16¾ tons. It has double sliding doors at each end with openings 3 feet 5 inches wide, and single slidings doors, one in the middle of each side, with 2 feet 8 inches opening. There are 40 barred seats placed in line along each side, and an aisle 4 feet 8 inches wide between the seats; with the seats, aisle and platforms fully occupied, 150 persons have been carried. The car is lighted by eight argand lamps, arranged in three clusters and burning mineral oil. In cold weather, the car is heated by one hot water heater, with two lines of wrought iron pipes 1¼ inches in diameter under each line of seats.

12th.—The Grip first used.*—As employed on the Railway, the grip consists essentially of the sheaves which grasp the cable, the brakes which prevent the sheaves from revolving, the levers by which the pressure is applied and the frame which holds the moving parts. The grip first used, shown in Plate XX, is described as follows: There are four sheaves placed in pairs, so that the cable is gripped between each pair; each sheave runs loosely on a short, fixed pin and has a heavy grooved rim with cylindrical inner surface, against which the brake presses; this rim is in two parts bolted together and holds in a dovetailed groove a packing of leather and india rubber belting in alternate pieces placed radially; the packing projects well out from the rim and is grooved to receive the cable. There are also four brakes, one for each sheave, of hard wood and with a curved outer face fitted to the inside of the rim of the sheave; each brake is held by a lever and the four levers are connected to the two operating levers, which are so pivoted that their short arms form a toggle. The frame is made up of flat wrought iron bars, bolted together and also hinged, so as to permit

* In a "Communication from the Chief Engineer in Regard to the Method of Steam Transit over the East River Bridge, made to the Board of Trustees, March 4, 1878," is the following: "For the circulating system, the engine is run continuously in one direction; the rope is spliced endless, and the tracks at the termini are connected by a short switch, the empty cars being transferred from one track to the other by a horse or steam power. For securing the car to the running rope, many patent contrivances exist, but as there are no stoppages on the way, the simplest method will be—a short piece of manilla rope, one end of which is fastened to the car, then taking a half hitch around the wire rope, the driver holds one end with one hand and the brake with the other, and thus has full control over the car. This was in use many years ago on the old Portage Railway over the Alleghany mountains, but for a high rate of speed its application might be somewhat doubtful."

the necessary movements of the sheaves and brakes. Adjustments to take up wear and restore the proper relative positions of the operating parts are made by hand screws placed in the connections of the frame. The long arms of the operating levers are moved towards each other or apart, to close or open the grip, by means of a small endless cable, one line being attached to the end of each lever; this cable is underneath the car, and at each platform a sprocket chain forming a part of the cable is wound around a sprocket wheel, which is on the lower end of the brake shaft. The arrangement of operating levers, cables and winding gear is shown in Plates XXII and XXIV. It will be seen, that in operating the grip, as it is closed the sheaves are brought into contact with the cable and revolve at cable speed; the car being at rest, the brakes force the sheaves together with increasing pressure, which, transmitted to the sheaves from the brakes, develops a frictional resistance tending to prevent the sheaves from revolving, and this continues until such resistance in the four sheaves exceeds the tractive resistance of the car, when the sheaves cease to revolve and the car moves at cable speed. The grip is bolted underneath the car floor, as shown in Plate XXIV, about midway between the trucks, with the plane of the sheaves inclined 22 degrees from the horizontal, and one side of the frame is fixed by adjustable stay rods, reaching down from the car bottom. A trip gear was provided, shown in Plate XX, for releasing the cable without moving the operating levers; it was worked either by hand or by a third lever, which came into contact with a stop fixed along side of the track, at a point where the cable should be dropped.

13th.—The Grip now used.—For the grip above described, was substituted the one now employed, shown in Plate XXI, and differing from the first, in having comparatively long shafts for the sheaves, a strong rigid frame for the operating parts, and a self adjusting device whereby the relative position of the pieces subject to wear, is automatically preserved; a packed vise grip and means for grasping the cable at the tilting pulleys, while the car is in motion or at rest, were added, and the trip gear was omitted. The sheaves are each keyed to one end of a steel shaft which runs in two closed bearings, so arranged that when a sheave is to be taken out for repair or other purpose, it and its shaft may be quickly removed and replaced by another, if need be, in working condition. The main frame is in two parts, each hinged in a common line parallel to the cable, close under the car floor, one part hanging on each side of the cable. The sheaves, each are carried by a small frame, hinged from its part of the main frame, in a line parallel to the sheave's shaft; this small frame has a limited movement, opposed by a coiled spring, which tends to force the sheave away from its brake; each of the four brakes is held by a projecting end of the main frame; the vise grip is in two parts, each being on the inner face of the lower bar of a part of the main frame; it is packed in the same manner as are the

sheaves. The uppermost part of the main frame, that from which the operating levers project, is fixed in position by adjustable stay rods; the movable part is connected to the levers by a coarse threaded screw, which is turned by a rachet wheel and pawl. It will be observed, that as the grip is used, the packed grooves in the sheaves are slowly compressed and worn, thereby permitting when the grip is closed, the sheaves to come more nearly together, and the short arms of the operating levers to approach more closely to a straight line; and as this continues the pressure on the packed surfaces increases rapidly. Such action is prevented, when as the grip is closed, a certain position of the levers in approaching each other is passed, by the pawl engaging with a tooth of the ratchet wheel, then as the levers are separated, the screw is turned slightly, which brings the sheave surfaces and the levers to their former and normal relative positions. The frames are of cast steel, with fixed joints, and stiffened where the greatest stresses are resisted. The vise grip which grasps the cable only as the frames and the sheave packings yield, is intended to take full hold after the sheaves cease to revolve and the car is moving at cable speed; the trains start from the Stations on a descending grade, and this increase in the tractive power of the grip was thought to be needed when they reach the ascending grade. Suspended from the fixed part of the frame, is the bent inverted rail, also of cast steel, which comes into contact with the flat-faced idle pulleys on the tilting pulley frames; to prevent the cable from being lifted above the grip sheaves when these pulleys are elevated, a small stop pulley is put near each end of this rail; these pulleys are made up of flat rings of leather and india rubber, forced on to a cast iron spool, which runs loosely on a fixed pin.

The packings for the grip are cut in a punching machine driven by power, from the material in sheets, with a sharp die, shaped to fit the contour of the piece; the pieces are put together under pressure, and well tacked with wire nails, as piece after piece is laid on; the packings so formed are kept in stock, and when used they are forced into place. For the sheaves, the packing is made up in two equal sections, and when in the sheaves the material has been compressed about $2\frac{1}{2}$ inches in a circumference of 15 inches mean diameter, so that as the leather tends to swell from moisture absorbed in wet weather and shrink as this evaporates, the elasticity of the india rubber keeps the packing intact and the pieces closely in contact. As the grooves wear deeper, the projecting parts are turned off so as not to interfere with the closing of the grip, and if necessary the groove is also trued; thus a large part of the material is finally used before the packing is thrown aside and a new one put in the sheave.

14th.—The Brakes.—By the usual arrangement of levers and rods, shown in Plate XXIV, a brake is applied to each car wheel; the whole being operated by hand or a partial vacuum. A hand wheel and

shaft on each platform, by means of a lever and clutch (see Plate XXII) are connected with either the grip or brake gear; the sprocket wheel which opens and closes the grip, and the cylinder which winds the brake chain, each being loose on the hand wheel shaft; the one or the other being fixed for the time, as this shaft is elevated or depressed by the lever. For the vacuum apparatus, there is a diaphragm chamber on each truck and a reservoir underneath and attached to the car body. A chain connects each diaphragm with a brake lever on the truck and pipes connect the two diaphragm chambers with the reservoir; these pipes run to each end of the car, where by means of a three way cock under the platform and a small hand lever, pressure is applied to the brakes or released. At first the reservoir was exhausted by connecting it with a vacuum ejector on a locomotive; this was done while the car in its trips, was stopping at Brooklyn Station; afterwards a pump, shown in Plate XXV, was put on, and each car maintains the requisite tension in its reservoir. The pump is attached to the underside of one truck and is driven from a car axle by an eccentric; it is single acting and has a trunk piston; the cylinder is 5 inches in diameter and the stroke 5½ inches long. By this pump, in running the car less than 1 000 feet after the brakes have been applied, the tension in the reservoir is restored, and a working vacuum of from 12½ to 13¾ pounds readily maintained, sufficient for all demands. Ordinarily the tension in the reservoir is reduced by applying the brakes, from 2½ to 3 pounds.

Before this attachment was put on, the vacuum was reserved for emergencies, and only applied then, whenever the hand brakes failed, or occasionally to determine that the parts were in working order; now the vacuum is generally used in operating the brakes. It will be noticed the mechanism described is not in duplicate; the brakes, levers, rods and their connecting parts being common to the two brake systems; that each car has its own apparatus which is operated independently of that on other cars in a train; and that the brakes cannot be applied until the grip is released.

15th.—The Locomotives.—To haul the trains to and from the storage platform or from one main track to the other at the Stations, over the Railway during the day whenever the cable from any cause is not running, and late at night when the traffic is lightest and the cable is stopped, four-wheel tank switching locomotives are used; that is, they are without tenders; the entire weight, including that of the coal and water carried, being on the four driving wheels. At first there were two, each weighing, when loaded, 9 tons, with steam cylinders 9 inches in diameter and 14 inches stroke, driving wheels 36 inches in diameter, and wheel base 5 feet 9 inches long; and two others, weighing, when loaded, 13 and 14 tons, with steam cylinders and driving wheels as before mentioned, and wheel base 6 feet long. As the traffic increased

and longer trains were run, these were replaced by heavier locomotives. Now there are employed three, each weighing when loaded, 21½ tons, with steam cylinders 11 inches in diameter and 16 inches stroke, driving wheels 38 inches in diameter and wheel base 6 feet long; and two others, weighing when loaded, 22 and 23 tons, with steam cylinders 12 inches in diameter and 16 inches stroke, the driving wheels and wheel base being as last mentioned. Four of these locomotives are in constant use; when necessary one will haul a train of two loaded cars, at cable speed, over the railway. The locomotives and cars are all fitted with the automatic car coupler, shown with the link, in Plate XXIII. The sidings and connecting lines are laid with Lorenz or point switches; generally at each Station, they are operated from one place or switch house.

16th.—The Auxiliary Cable Plant.—To switch trains in New York Station from one main track to the other, a pair of continuous cables ¾ inches in diameter were used for several months after the opening of the Railway, one cable along each of the two switches. The hauling lines of these cables, between the tracks, were placed 8 inches apart; that is, 4 inches on one or the other side of the centre line of track. The driving plant is shown in Plate XVII ; the arrangement of the cables and their pulleys, and the position of the switches are shown in Plate VIII. Each cable was driven by a pair of winding drums 4 feet in diameter, which were loose on the shafts of the two sheaves under the northerly main track; a pair of drums on each side of the sheaves. The main cable so passed around these sheaves, that they revolved in opposite directions; the drums were driven by means of friction clutches, which were engaged or disengaged by a system of levers and rods, terminating at a point where an attendant could operate it; one drum being clutched to its sheaves, would haul the cable in one direction and the other drum of the pair being clutched to its sheave would haul the cable in the contrary direction; but one drum driving at a time and the other of the pair running loosely, the two clutches being operated by one lever. The friction clutch used consisted of a steel hoop attached to the driving shaft, 4 inches wide, 1½ inches thick and 42½ inches in diameter; this was cut apart at one place, and between the ends thus formed a wedge was forced outward by means of a toggle, so that the hoop was expanded into close contact with the inside projecting cylindrical surface of the drum cylinder. The auxiliary cables ran at a speed of 4 miles per hour; to each a small grip car was permanently attached by a vise grip; each car ran to and fro on its own line of track as the drums were operated, and the trains to be switched were hauled by these cars. For the auxiliary cable plant thus described was substituted that shown in Plates XVIII and XIX, differing from the first in having the drums entirely detached from the sheaves, except when the clutches were engaged; providing a shaft for each drum, with large bearings and adjustable pillow blocks; and a frame which allowed renewal of the

several parts, piece by piece, without interfering with the use of the remaining plant; also other modifications for convenience and utility. So far, this plant has not been put in operation.

## II.—TRAFFIC AND OPERATION.

17th.—Train Service.—The number of trains run daily and of cars in each train, has steadily increased since the Railway was first operated; the traffic offered however, fluctuates greatly; being affected by the occasion and the weather, as well as the time of day, the day of the week and the season. The first train—of one car—ran over the Railway, August 8, 1883; the following day five trips were made, and passengers were first taken September 24. Two-car trains were run October 28, 1883, and three-car trains September 15, 1885. Trains were first run during the busy hours morning and evening, on 1½ minutes headway, March 5, 1885, and on 1¼ minutes headway, March 2, 1886. Experimentally, 3 three-car and 10 two-car trains were run on 1¼ minutes headway, 1½ hours in the morning and 2 hours in the evening, September 27, 1886. Usually however, the minimum headway during the day's run is 1½ minutes. Table I, compiled from the train dispatcher's daily record, giving the number, order and headway of trains sent out from Brooklyn Station during the days mentioned, exhibits fairly the past and present operation of the Railway; it being noticed that the same trains were also sent out and in the same order from New York Station.

Interruptions and delays in handling the traffic on a railway like this, must necessarily from time to time occur; a summary of the causes and extent of such during the four years and five months ending April 30, 1888, or nearly the whole term the railway has been operated, is given in Tables II and III; the times therein recorded being those during which travel was entirely stopped; usually when the delay is likely to be unduly prolonged, trains are run in the intervals by locomotives. By these Tables, it appears that of the total time lost by delays in the terms referred to, that due to the cable system decreased from about 77 per cent. for the five months ending April 30, 1884 to about 24 per cent. for the year ending April 30, 1888; and for the whole time covered by the Tables, it was about 44 per cent. In Table III it is intended to show at a glance, how inconsiderable the average loss from delays at any time has been to the single passenger; it will be seen that this loss has steadily decreased since the Railway was first opened to traffic.

The Railway has been operated with great safety to passengers and trainmen; the only accident which caused serious injury to either, occurred on a wet and sleety morning, December 5, 1885. A train from Brooklyn to New York dropped the cable at the Brooklyn pier; the following train ran to within 100 feet of it and stopped, the brakes were released and the train was permitted to run back on the down grade with too great speed; it collided with a third train, breaking platforms and

TABLE I.—NUMBER AND HEADWAY OF TRAINS.

| Tuesday, April 29, 1884. From 5 A.M. to 12 50 A.M. 19 hours, 50 minutes. | | | | Tuesday, April 27, 1886. From 12 A.M. to 12 A.M. 24 hours. | | | | Tuesday, May 1, 1888. From 12 A.M. to 12 A.M. 24 hours. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of trains. | Number of cars in train. | Headway. | Power employed. | Number of trains. | Number of cars in train. | Headway. | Power employed. | Number of trains. | Number of cars in train. | Headway. | Power employed. |
| | | Min. sec. | | | | Min. sec. | | | | Min. sec. | |
| 13 | 1 | 5 — 0 | Cable. | 12 | 1 | 4 — 0 | Cable. | 12 | 2 | 4 — 0 | Cable. |
| 15 | " | 4 — 0 | " | 17 | " | 15 — 0 | Loco. | 9 | " | 15 — 0 | Loco. |
| 5 | 2 | 3 — 0 | " | 16 | " | 4 — 0 | Cable. | 8 | 1 | " " | Cable. |
| 6 | " | 2 —30 | " | 9 | 2 | 3 — 0 | " | 16 | 2 | 4 — 0 | " |
| 53 | " | 2 — 0 | " | 94 | " | 1 —30 | " | 9 | 3 | 3 — 0 | " |
| 6 | " | 2 —30 | " | 46 | 3 | | " | 149 | " | 1 —30 | " |
| 10 | " | 3 — 0 | " | 24 | " | 2 —30 | " | 138 | " | 3 — 0 | " |
| 7 | " | 4 — 0 | " | 18 | 2 | | " | 72 | " | 1 —30 | " |
| 54 | " | 5 — 0 | " | 90 | " | 3 — 0 | " | 18 | " | 3 — 0 | " |
| 15 | " | 4 — 0 | " | 73 | " | 1 —30 | " | 10 | " | 4 — 0 | " |
| 20 | " | 3 — 0 | " | 37 | 3 | | " | 55 | 2 | " " | " |
| 32 | " | 2 —30 | " | 20 | 2 | 3 — 0 | " | | | | |
| 27 | 1 | 3 — 0 | " | 53 | " | 4 — 0 | " | | | | |
| 20 | " | 4 — 0 | " | 6 | 1 | " " | " | | | | |
| 46 | " | 5 — 0 | " | | | | " | | | | |
| 329 trains, 537 cars. | | | | 515 trains, 1 092 cars. | | | | 487 trains, 1 353 cars. | | | |

ends from one car, one platform and end from another car, and other platforms more or less. The cars were crowded, passengers being on all but the front platforms of the trains, and two persons were seriously injured, one being a brakeman. The cars had to be separated by force before one of the injured was released; he, a passenger, having a foot crushed by being caught between two platforms, sliding one over the other. The accident was due to the brakemen on the middle train (one of whom was so badly hurt) becoming confused and not applying the brakes, in time. Collisions sometimes happen, of which this is a rare instance. About 6-30 o'clock P. M. February 12, 1886, just after an incoming train at Brooklyn Station was moved from the platform, the locomotive hauling it, jumped the switch. The following train, crowded with passengers, ran into the first with considerable shock, but without greater injury to the passengers, than a few bruises; the third train was brought up in time. This accident was due to the enforced stoppage of the first train.

18th.—Passengers Carried.—The number of passengers carried each calendar month, from the opening of the Railway, to and including April, 1888, is given in Table IV; it may be stated that the fare was five cents until March 1, 1885, when it was reduced to three cents, or to ten tickets for twenty-five cents. By this Table, it appears that the number has increased in the four years ending with September, over 244 per cent., and ending with February, over 211 per cent. An interesting local inquiry is how long and at what rate, will this traffic continue to increase. So far as a reference to the past traffic will aid in considering a reply, the number of passengers carried in each period of twenty-eight days, or lunar month, as exhibited by the diagram on page 82, will serve better than the data given in Table IV.

During the day of 24 hours, the traffic over the Railway ebbs and flows in an irregular and greatly varient tide; this appears from the number of cars in the trains run and the headways; the loads on the trains are heavier in the morning on those from Brooklyn, and in the afternoon on those from New York; for a part of each time, the cars moving one way will be densely crowded, and those moving the other way will be perhaps not one-fourth full; during other intervals, the travel in the two directions may be nearly equal. The number of passengers carried each day of 24 hours is regularly taken and recorded; at certain times, the number during specific hours has been counted, and from the data thus obtained Tables V and VI were collated, showing the fluctuation and relative proportions of daily travel at different periods. The mean per cents. given in Table V, correspond quite closely to similar per cents. for the several days mentioned. From the Table, it will be seen that about 82 per cent. of the total traffic is carried in the 12 hours from 7 o'clock A.M. to 7 o'clock P.M., and about 22 per cent. in one-sixth of this time, the maximum morning and evening hour. The number of passengers each way, carried each hour of two days, about 18 months apart, is given in Table VI, and is for the even hour as noted in the first column; the maximum number is 10 068 passengers carried from Brooklyn to New York, between 7 and 8 o'clock A.M., November 29, 1887. During the morning and evening rush, when the travel for a short time is greatly concentrated, this may be exceeded; thus in the sixty minutes between 5–30 and 6–30 o'clock P.M., Monday, November 18, 1887, 12 160 passengers from New York to Brooklyn were carried.*

* As the stations and train platforms are now arranged, passengers may crowd upon the latter, until the available space near to the outgoing train is closely occupied; and consequently during the rush hours a few trains may be overloaded. At the time above mentioned, trains of three cars each on 1½ minutes headway or 120 cars per hour were running: whence if the movement of passengers to the trains were regulated and only so many as could be comfortably carried, admitted at one time to the platform, each car would have had but about 100 passengers, there need not have been any crowding, and no one would have been delayed over one headway.

## TABLE II.—CAUSES AND EXTENT OF DELAYS.

| Term. | 5 months ending April 30, 1884. | | Year ending April 30, 1885. | | Year ending April 30, 1886. | | Year ending April 30, 1887. | | Year ending April 30, 1888. | | 4 years and 5 months ending April 30, 1888. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Causes of Delays. | No. | Time lost. | No. | Time lost | No. | Time lost. | No. | Time lost. | No. | Time lost. | No. | Time lost. |
| | | H. M. | | H. M. | | H. M. | | H. M. | | H. M. | | H. M. |
| Auxiliary cable car failed | 5 | 0—56 | .. | ..... | ... | ..... | .. | ..... | .. | ..... | 5 | 0—56 |
| " drum stuck | .. | ..... | 1 | 0—35 | ... | ..... | .. | ..... | .. | ..... | 1 | 0—35 |
| Cable dropped at tilting pulleys | .. | ..... | .. | ..... | 1 | 0— 7 | .. | ..... | .. | ..... | 1 | 0— 7 |
| " elsewhere | 12 | 1—52 | 7 | 1—29 | ... | ..... | 1 | 0— 3 | .. | ..... | 20 | 3—24 |
| frozen fast | 1 | 0— 4 | .. | ..... | ... | ..... | .. | ..... | .. | ..... | 1 | 0— 4 |
| not caught by grip | .. | ..... | .. | ..... | ... | ..... | 6 | 0—24 | 6 | 0—19 | 12 | 0—43 |
| slipped on driving drum | .. | ..... | 1 | 0—35 | ... | ..... | .. | ..... | .. | ... .. | 1 | 0—35 |
| thrown from tilting pulleys | .. | ..... | .. | ..... | 6 | 0—27 | 5 | 0—30 | 16 | 0—42 | 27 | 1—39 |
| Driving engine overloaded | .. | ..... | .. | ..... | ... | ..... | .. | ..... | 4 | 1—27 | 4 | 1—27 |
| stopped by hot bearing | 3 | 0—59 | 1 | 0— 2 | 1 | 0— 5 | .. | ..... | 1 | 0— 7 | 6 | 1—13 |
| " from other causes | 1 | 0— 5 | 1 | 0— 6 | ... | ..... | .. | ..... | 1 | 0—10 | 3 | 0—21 |
| Grip frame or gear, failed | 5 | 0—31 | 3 | 0—30 | 14 | 1—31 | 4 | 0—12 | 1 | 0— 3 | 27 | 2—47 |
| out of place | .. | ..... | .. | ..... | 14 | 0—44 | 1 | 0— 3 | 2 | 0—14 | 17 | 1— 1 |
| sheaves worn | 1 | 0— 5 | 1 | 0— 8 | 1 | 0—10 | .. | ..... | .. | ..... | 3 | 0—23 |
| not closed | .. | ..... | 1 | 0— 5 | 37 | 2—38 | .. | ..... | .. | ..... | 38 | 2—43 |
| " released | 1 | 0—14 | 2 | 0—58 | 1 | 0— 5 | 3 | 0— 6 | .. | ..... | 7 | 1—23 |
| slipped, cause not stated | .. | ..... | .. | ..... | 6 | 0—37 | 3 | 0—13 | .. | ..... | 9 | 0—50 |
| Total, caused by grips | 7 | 0—50 | 7 | 1—41 | 73 | 5—45 | 11 | 0—34 | 3 | 0—17 | 101 | 9— 7 |
| Tension car derailed or out of order | .. | ..... | .. | ..... | ... | ..... | 2 | 0—35 | .. | ..... | 2 | 0—35 |
| Total, caused by entire cable system | 29 | 4—46 | 18 | 4—28 | 81 | 6—24 | 25 | 2— 6 | 31 | 3— 2 | 184 | 20—46 |
| Accident to passenger | .. | ..... | .. | ..... | ... | ..... | .. | ..... | 1 | 0— 5 | 1 | 0— 5 |
| Block signal, out of order | .. | ..... | .. | ..... | 2 | 0—12 | .. | ..... | .. | ..... | 2 | 0—12 |
| Brake gear failed | 1 | 0— 8 | .. | ..... | 3 | 0— 6 | 7 | 0—20 | 4 | 0—13 | 15 | 0—47 |
| " frozen fast | .. | ..... | .. | ..... | 2 | 0— 8 | 2 | 0— 9 | .. | ..... | 4 | 0—17 |
| vacuum leaked | .. | ..... | .. | ..... | ... | ..... | 1 | 0—25 | .. | ..... | 1 | 0—25 |
| Brakes not released | .. | ..... | .. | ..... | 2 | 0— 6 | 1 | 0— 4 | .. | ..... | 3 | 0—10 |
| Car axle broken | .. | ..... | .. | ..... | ... | ..... | .. | ..... | 1 | 0—15 | 1 | 0—15 |
| wheel flattened | .. | ..... | .. | ..... | .. | ..... | 1 | 0— 2 | .. | ..... | 1 | 0— 2 |
| Collision, switch misplaced | .. | ..... | 1 | ..... | ... | ..... | .. | ..... | 1 | 0— 2 | 1 | 0— 2 |
| from other causes | 3 | 0—36 | .. | 0—10 | 6 | 1— 6 | 2 | 0—17 | 1 | 0— 3 | 13 | 2—12 |
| Derailment, from snow and ice | .. | ..... | .. | ..... | ... | ..... | .. | ..... | 1 | 1—25 | 1 | 1—25 |
| " switch misplaced | .. | ..... | 4 | ..... | 4 | 1—40 | 3 | 0—59 | 3 | 0—46 | 10 | 3—25 |
| " " not adjusted | .. | ..... | 6 | 1—57 | 4 | 0—23 | 8 | 2—53 | 16 | 2— 7 | 32 | 7—20 |
| cause not stated | 1 | 0—30 | .. | 0—43 | 16 | 5— 9 | .. | ..... | .. | ..... | 23 | 6—22 |
| Drawbar broken | .. | ..... | .. | ..... | ... | ..... | 18 | 0—47 | 14 | 0—28 | 32 | 1—15 |
| caught on truck | .. | ..... | .. | ..... | ... | ..... | .. | ..... | 1 | 0— 3 | 1 | 0— 3 |
| pulled out | .. | ..... | .. | ..... | 1 | 0— 4 | 4 | 0—12 | .. | ..... | 5 | 0—16 |
| Locomotive, out of order or steam | 1 | 0—10 | .. | ..... | 1 | 0— 5 | 4 | 0—47 | .. | ..... | 6 | 1— 2 |
| Train too long or ran too far | .. | ..... | .. | ..... | ... | ..... | 1 | 0— 4 | 1 | 0— 4 | 2 | 0— 8 |
| ran into bumper | .. | ..... | .. | ..... | ... | ..... | .. | ..... | 1 | 0— 3 | 1 | 0— 3 |
| stalled on crossing | .. | ..... | .. | ..... | ... | ..... | .. | ..... | 1 | 0—14 | 1 | 0—14 |
| uncoupled | .. | ..... | .. | ..... | ... | ..... | .. | ..... | 1 | 0— 6 | 1 | 0— 6 |
| Total from causes independent of cable system | 6 | 1—24 | 11 | 2—50 | 41 | 8—59 | 52 | 6—59 | 47 | 5—54 | 157 | 26— 6 |
| Total from all causes | 35 | 6—10 | 29 | 7—18 | 122 | 15—23 | 77 | 9— 5 | 78 | 8—56 | 341 | 46—52 |
| Total preventable at the time | 4 | 0—40 | 10 | 3—22 | 52 | 5—57 | 16 | 1—47 | 22 | 1—53 | 104 | 13—39 |

TABLE III.—NUMBER OF PASSENGERS WHO FROM DELAYS, COLLECTIVELY LOST ONE SECOND, DURING THE TERM MENTIONED.

| Term. | 5 months ending April 30, 1884. | Year ending April 30, 1885. | Year ending April 30, 1886. | Year ending April 30, 1887. | Year ending Apr 1 30, 1888. | 4 years and 5 months ending April 30, 1888. |
|---|---|---|---|---|---|---|
| Passengers carried..... | 3 475 421 | 10 503 237 | 21 300 866 | 26 036 464 | 29 021 571 | 90 337 558 |
| Delays | Number of passengers. | | | | | |
| Due to the grip..... | 825 | 1 733 | 1 029 | 12 763 | 28 451 | 2 753 |
| " entire cable system..... | 144 | 653 | 925 | 3 444 | 2 658 | 1 208 |
| " remaining railway service..... | 491 | 1 030 | 659 | 1 036 | 1 366 | 962 |
| " entire railway service..... | 112 | 400 | 385 | 796 | 902 | 536 |
| Preventable at the time..... | 1 031 | 867 | 994 | 4 056 | 4 281 | 1 838 |

TABLE IV.—PASSENGERS CARRIED EACH MONTH.

| | 1883–84. | 1884–85. | 1885–86. | 1886–87. | 1887–88. |
|---|---|---|---|---|---|
| October..... | 477 700 | 816 220 | 1 958 495 | 2 317 392 | 2 635 617 |
| November..... | 561 520 | 797 640 | 1 868 088 | 2 270 026 | 2 514 184 |
| December..... | 600 440 | 898 800 | 1 873 316 | 2 322 373 | 2 620 609 |
| January..... | 663 840 | 889 420 | 1 828 517 | 2 321 896 | 2 521 786 |
| February..... | 723 740 | 904 650 | 1 778 584 | 2 123 129 | 2 436 694 |
| March..... | 735 180 | 1 353 557 | 2 084 715 | 2 433 069 | 2 488 892 |
| April..... | 752 220 | 1 402 390 | 2 007 498 | 2 379 360 | 2 593 104 |
| May..... | 766 420 | 1 535 080 | 2 080 634 | 2 432 978 | ..... |
| June..... | 693 260 | 1 541 277 | 1 991 979 | 2 253 172 | ..... |
| July..... | 624 900 | 1 461 375 | 1 846 829 | 2 005 719 | ..... |
| August..... | 645 760 | 1 619 832 | 1 893 304 | 2 161 083 | ..... |
| September..... | 710 220 | 1 744 089 | 2 056 473 | 2 357 733 | ..... |
| Total for year ending with September..... | 7 955 200 | 14 964 330 | 23 268 432 | 27 377 930 | ..... |
| Total for year ending with February..... | 9 234 690 | 19 964 600 | 25 316 248 | 28 752 004 | |

DIAGRAM SHOWING FLUCTUATION OF PASSENGER TRAFFIC, FROM DECEMBER 1, 1884, TO APRIL 15, 1888.

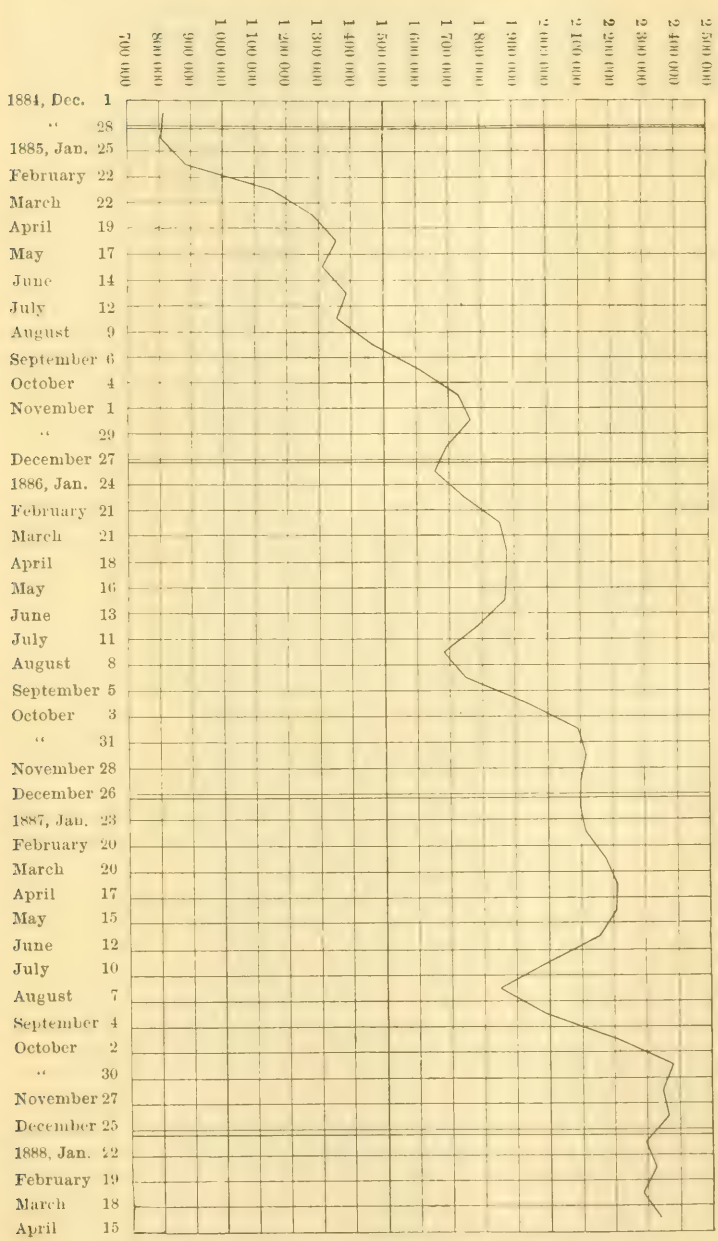

TABLE V.—PASSENGERS CARRIED CERTAIN DAYS AND PARTS OF DAYS.

| Day. | From New York. | | | | From Brooklyn. | | | | Total carried in 24 hours. | Train service. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Maximum in one hour. | Between 7 A.M. and 7 P.M. | Between 7 P.M. and 7 A.M. | In 24 hours. | Maximum in one hour. | Between 7 A.M. and 7 P.M. | Between 7 P.M. and 7 A.M. | In 24 hours. | | Time that the trains ran. | Hours that the trains ran. |
| 1883. Oct. 18.. | 1 420 | 5 950 | 1 270 | 7 220 | 1 560 | 7 840 | 1 440 | 9 280 | 16 500 | 6 A.M.–12 P.M. | 18 |
| 1884. Feb. 27. | 2 174 | 7 070 | 2 090 | 9 160 | 3 073 | 1 780 | 2 060 | 13 840 | 23 000 | 6 A.M.– 1 A.M. | 19 |
| Mar. 25. | 2 325 | 8 990 | 2 290 | 11 280 | 2 765 | 11 740 | 2 220 | 13 960 | 25 240 | " " | " |
| April 28. | 2 405 | 9 180 | 2 440 | 11 620 | 3 090 | 12 220 | 2 260 | 14 480 | 26 100 | 5 A.M.– 1 A.M. | 20 |
| May 20. | 2 503 | 8 930 | 2 210 | 11 140 | 3 006 | 11 710 | 2 450 | 14 160 | 25 300 | " " | " |
| June 25. | 2 480 | 8 060 | 1 820 | 9 880 | 3 950 | 9 690 | 2 670 | 12 360 | 22 240 | " " | " |
| July 17. | 2 150 | 7 430 | 1 910 | 9 340 | 2 570 | 9 840 | 2 140 | 11 980 | 21 320 | " " | " |
| Aug. 13. | 2 085 | 7 990 | 1 970 | 9 960 | 2 496 | 9 960 | 2 400 | 12 360 | 22 320 | " " | " |
| Sept. 17. | 2 512 | 9 060 | 2 130 | 11 190 | 3 005 | 11 587 | 2 300 | 13 887 | 25 077 | " " | " |
| Oct. 11. | 2 710 | 10 247 | 2 830 | 13 077 | 3 280 | 13 285 | 2 750 | 16 035 | 29 112 | " " | " |
| Nov. 17. | 2 980 | 10 515 | 2 175 | 12 690 | 3 709 | 13 854 | 2 250 | 16 104 | 28 794 | " " | " |
| Dec. 20. | 3 480 | 10 683 | 2 845 | 13 528 | 4 620 | 16 211 | 2 195 | 18 406 | 31 934 | 12 P.M.–12. P.M. | 24 |
| 1885. Feb. 24. | 3 473 | 12 608 | 3 220 | 15 828 | 4 725 | 17 883 | 2 800 | 20 683 | 36 511 | " " | " |
| 1886. May 25. | 7 187 | 25 306 | 6 840 | 32 146 | 7 870 | 30 807 | 7 284 | 38 091 | 70 237 | " " | " |
| 1887. Nov. 29. | 9 402 | 33 516 | 9 200 | 42 716 | 10 068 | 40 721 | 7 693 | 48 414 | 91 130 | " " | " |
| Mean per cents. in 24 hours. | 22.3 | 79.5 | 20.5 | 100. | 21.8 | 83.6 | 16.4 | 100. | | Carried one way. | |
| | 10. | 35.5 | 9.1 | 44.6 | 12.1 | 46.3 | 9.1 | 55.4 | 100. | Carried both ways. | |

19th.—Power Expended.—Observations from time to time have been made, to determine the power expended in hauling the cable. For two days in November, 1883, during the afternoon hour when the travel was the greatest, indicator cards were taken from the driving engine at short intervals; at the same time the movement of the trains and the number of passengers each carried were noted, and from the data thus obtained, the two diagrams, Plates XXIX and XXX were prepared. In these, the paths of the trains are shown by the broken lines, the engine horse-powers by the irregular full lines, and the times the cards were taken by the small circles. The profile underneath each diagram serves to locate the trains at any particular moment of their passage over the Railway. During the entire working day, 19½ hours, April 26, 1886, also before and after the trains were put on

TABLE VI.—PASSENGERS CARRIED EACH HOUR OF THE DAY.

| Hour beginning at | Tuesday, May 25, 1886. | | | Tuesday, November 29, 1887. | | |
|---|---|---|---|---|---|---|
| | From New York. | From Brooklyn. | Totals. | From New York. | From Brooklyn. | Tota's. |
| 12 P M. | 320 | 155 | 475 | 389 | 197 | 586 |
| 1 A.M. | 195 | 104 | 299 | 249 | 62 | 311 |
| 2 " | 158 | 131 | 289 | 211 | 80 | 291 |
| 3 " | 93 | 129 | 222 | 111 | 128 | 239 |
| 4 " | 112 | 144 | 256 | 112 | 139 | 251 |
| 5 " | 127 | 432 | 559 | 143 | 370 | 513 |
| 6 " | 410 | 2 708 | 3 118 | 469 | 2 894 | 3 363 |
| 7 " | 505 | 7 870 | 8 375 | 841 | 9 366 | 10 207 |
| 8 " | 645 | 7 483 | 8 128 | 712 | 10 068 | 10 780 |
| 9 " | 746 | 3 489 | 4 235 | 1 007 | 4 589 | 5 596 |
| 10 " | 799 | 1 834 | 2 633 | 1 144 | 2 776 | 3 920 |
| 11 " | 968 | 1 450 | 2 418 | 1 333 | 2 267 | 3 600 |
| 12 M. | 1 033 | 1 275 | 2 308 | 1 345 | 1 618 | 2 963 |
| 1 P.M. | 1 012 | 1 480 | 2 492 | 1 416 | 1 969 | 3 385 |
| 2 " | 1 361 | 1 601 | 2 962 | 1 620 | 1 687 | 3 307 |
| 3 " | 1 662 | 1 227 | 2 889 | 2 109 | 1 897 | 4 006 |
| 4 " | 2 294 | 1 061 | 3 355 | 4 068 | 1 843 | 5 911 |
| 5 " | 7 094 | 1 113 | 8 207 | 9 402 | 1 580 | 10 982 |
| 6 " | 7 187 | 924 | 8 111 | 8 519 | 1 121 | 9 640 |
| 7 " | 1 921 | 1 101 | 3 022 | 2 251 | 1 402 | 3 653 |
| 8 " | 915 | 711 | 1 626 | 1 373 | 652 | 2 025 |
| 9 " | 855 | 598 | 1 453 | 1 314 | 562 | 1 876 |
| 10 " | 896 | 607 | 1 503 | 1 271 | 667 | 1 938 |
| 11 " | 838 | 464 | 1 302 | 1 307 | 480 | 1 787 |
| Total..... | 32 146 | 38 091 | 70 237 | 42 716 | 48 414 | 91 130 |

and taken off, indicator cards were taken from the driving engine, at half and quarter hour intervals ; the horse-powers so determined are shown by the diagram, Plate XXVIII ; representative cards, and one recording nearly the maximum power developed by the driving engine at any time are reproduced in Plate XXVII. Referring to the diagram, it will be seen that the indicated power used on the day mentioned, ranged from 303.1 horse-power maximum to 12.9 horse-power minimum and

negative; that the mean for the whole 19½ hours the trains were hauled was 96.2 horse-power; that for 5 hours from 7-30 to 9 o'clock A.M. and from 4-30 to 7 o'clock P.M. it was 150.5 horse-power, and for the remaining 14½ hours it was 74.4 horse-power; also to drive the plant without trains, it was 47.7 horse-power.

The diagram exhibits great and abrupt fluctuations of power; in one instance an increase of 190 horse-power within fifteen minutes, and in another, 239 horse-power within thirty minutes. There are also large differences in the power indicated at the two ends of the steam cylinder; this is, however not due as may at first be inferred, to an ill adjustment of the steam valves, since at one time the greater power is developed at one end, and at another time, at the other end of the cylinder. These variations of power are not unusual in the working of the driving engines; a brief observation in the engine room, when the cable is hauled, will show that the power applied often varies much more abruptly, at shorter intervals and between wider limits than here recorded. In explanation of this it may be said, that although the engines are equipped with an automatic valve gear of approved design, the regulation, under the quick and large changes in load, is slow and late, and therefore frequently too great in one direction or the other; as seen by an inspection of the Railway profile, Plate XXVI, the Stations are not at the same elevation, the summit is not midway between them, and the inclines leading from them are not alike; and lastly, the trains are almost always unequally laden, and often at unequal distances apart.

The diagram shows that five times during the working day observed, the indicator card taken was negative; at these and other times within the intervals at which the observations were made, the steam was cut off, perhaps the throttle valve was closed by the engineer in charge, and the engine was driven by the back haul from the outgoing line of cable; the preponderance of load at such time being on the down grades and in excess of the friction of the cable driving plant. This racing frequently occurs; generally when the travel is comparatively light, or when to lengthen the headway, trains are being removed. Usually it continues but a brief period, during which, however, the speed of the engine is sometimes greatly increased; thus on one occasion 56 revolutions were made one minute, 84 revolutions the second minute and 56 revolutions the third minute; whence the normal speed, 57 revolutions per minute was, in the short interval, nearly doubled. There being more and longer trains run now than formerly, as may be expected, the engine races more frequently.

The engines described and in use since the Railway was first operated, have singly furnished power sufficient for the maximum service; except on rare occasions, as for instance, in unfavorable weather, when the trains, heavily laden and frequent, in consequence of an interference with headway, were most of them moving up grade; and as has oc-

curred a few times, when the brakes were not released as the train was leaving a Station, or by a leakage in the air pipes, were applied while the train was in motion ; then the driving engine has slackened speed considerably, and even came almost or quite to a dead stop. The greatest power indicated by a single engine at any time is 394.5 horse-power.

20th.—Traction of Trains.—Observations made June 1 and 2, 1887, to see how far a train moved from a state of rest in acquiring full cable speed, gave 106.6 feet or about two-thirds the train length, as the mean of 11 tests, with trains of 3 cars. To determine how much of the power developed by the driving engine is expended in hauling the trains and how much in overcoming the friction of the cable driving plant, cars have been drawn over the Railway by locomotives, with a dynamometer substituted for the connecting link; the results thus obtained were diverse and unsatisfactory, and they are not here quoted. The following examination is based upon data given in the preceding Article and embodied in the diagram, Plate XXVII. During the 19½ hours the engine ran, April 26, 1886, there were hauled each way, 501 trains and 1 072 cars, weighing 11 256 tons; these carried from New York about 32 000 passengers, weighing (at 16 passengers per ton) 2 000 tons, and from Brooklyn, about 35 000 passengers, weighing 2 188 tons. While attached to the cable, the trains from New York to Brooklyn were raised 26.2 feet and from Brooklyn to New York, lowered 24.8 feet; these being the differences in elevations of the points where the grips were applied at one Station and released near the other Station. Using this data, the computed mean traction of the trains during the working day is equivalent to 37.5 horse-power;* the mean power developed by

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* Placing $G$ for the grade in feet per hundred or per cent., $n$ for number of cars in the train, $T$ for its weight in tons (of 2000 pounds) and $V$ for its speed in miles per hour; the resistances, $R$ in pounds, to be overcome in moving a train at uiform speed is expressed as follows: The axle or rolling friction may be taken at $5.4T$; the air pressure against the head of the train, at $0.28V^2$ and against the sides of the cars at $0.003nV^2$; the resistance due to oscillation and percussion at $0.006TV^2$, and the resistance due to grade at $20GT$. Collecting these, and writing $m$ as a multiplier of the co-efficients which may be subject to change ;

$$R = (5.6m \pm 20G)\ T + (0.28 + 0.03n + 0.006T)\ mV^2; \quad (a)$$

and for $V = 10$:

$$R = (6m \pm 20G)\ T + (3n + 28)m; \quad (b)$$

Comparing the results obtained by this formula with observations made on the traction of trains on the Railway, 1.3 was taken as a probable value of $m$; whence the equations become:

$$R = (7.2 \pm 20G)\ T + (0.36 + 0.04n + 0.008T)\ V^2; \quad (c)$$

and for $Ve = 10$:

$$R = (8 \pm 20G)\ T + 4n + 36, \quad (d)$$

In starting the train, the initial rolling friction for the first 100 feet, to be added to $7.2T$, is taken at 10 pounds per ton or $10T$; and in acquiring full speed, the resistance developed in the space the train thus moves (a function of the "velocity head" $\frac{V^2}{2g}$) becomes $68.85TV^2$.

the driving engine was 96.2 horse-power; or about one-eighth of the maximum power, taken as per indicator card, Plate XXVII, at 380.7 horse-power. It is assumed, in the absence of information to the contrary, that in addition to the friction of the plant itself, the loads impose an increase varying with them; placing $E$ for the maximum power of driving engine, $e$ for the power required to operate the plant without trains, $R$ for the traction of trains and $F$ for the coefficient of friction due to the latter; then $E = e + (1 + F)\,R$, and $F = \dfrac{E - e - R}{R}$. Substituting the numerical values given above, $F = 0.3$; whence the friction of the cable driving plant due to the traction of the trains was on the day mentioned, three-tenths of the load; and probably on other days does not vary greatly from this.

21st.—Hauling Power of the Drums.—The capacity of a cable driving plant, like that in operation on the Bridge Railway, is limited by the hauling power of the drums as well as by the motive power of the driving engine. In a few instances, similar to those referred to in the last paragraph of Article 20, when the engine was overloaded, the cable generally at the time being wet and dripping, it has slipped on the winding drums; if when this took place, the maximum power of the engine, say 380 horse-power was exerted—making due allowance for the friction of engine and drums—probably not more than 350 horse-power was transmitted to the incoming cable. This is equivalent to a direct haul of 13 125 pounds; the tension car causes a stress on each cable of about 1 785 pounds; whence the total resisting stress on the incoming cable would be greater than 14 910 pounds, of which the stress on the outgoing cable is less than 12 per cent.; this corresponds quite closely with the theoretical efficiency of a cable driven by one drum and wound as it is in this plant, the cable and grooves being not lubricated.* Since, however, when the cable has slipped on the drum (except in one instance), both were wet; without doubt, much less than the maximum power of the driving engine was then exerted.

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* The general problem in this case is: Given two drums, with a cable making one-fourth turn around the first drum, then in succession three or four half turns around each drum, and finally one-fourth turn around the second drum; required what tractive force may be exerted on the cable; the first and both drums being driven, and in each, with the cable and grooves fully lubricated, half lubricated and not lubricated. Placing for one groove, $P_1$ for the tension in the incoming and $p_1$ for that in the outgoing cable,

$$P_1 = p_1\, \epsilon^{af} \quad (e)$$

in which $f$ is the coefficient of friction between the cable and groove, taken with full lubrication at 0.1, with half lubrication at 0.15, and with no lubrication at 0.2; $a$ is the arc of contact of the cable and the particular groove with radius equal to unity, being therefore $\frac{\pi}{2}$ for one-fourth turn and $\pi$ for one-half turn; and $\epsilon$ is the base of the Naperian system of logarithms, whence $\epsilon^{af}$ is the number whose common logarithm is $\dfrac{af}{2.302585}$. From equation $(e)$, remembering that the stress on the cable outgoing from one groove is that on the cable incoming to the next or following groove; Table A is computed, in which the total stress on

## III.—WEAR, RENEWALS AND CHANGES.

22d.—Wear of Grooves in the Drums.—Soon after the Railway was first operated, (November 17, 1883) a counter, registering 100 000, was attached to the driving drum, and since a record of the revolutions daily made has been kept. From this, estimating the number of revolutions from the opening of the Railway to traffic (September 24, 1883) to the time the record began, at 1 275 250, and taking 12 feet as the mean diameter of the driving drum—whence each revolution equals 0.00714 miles, or 140 revolutions, one mile nearly—Table VII was compiled. Great pains were taken when the winding drums were made, to have the centers of the semicircular grooves for the cables of equal diameter and as nearly 12 feet as possible. The cylindrical face of each drum was carefully turned and the grooves fitted to a comb-shaped templet, which bearing against the face, entered each groove and gauged its depth. The accuracy of the work was tested by calliper-ing the drums at the bottoms of the grooves, and also by measuring their circumferences with a small revolving disk. The wear of the grooves was soon apparent, and from time to time was measured. February 2, 1884, the grooves of the driven drum were 0.02 inches less in diameter than those in the driving drum. The results of other measurements are given in Table VIII.

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the incoming cable, $P' = 1$. The values here given of $P - p$ and $p$, for "First drum driven" and "Four grooves," correspond to the case of the present cable driving plant; equation ($e$),

TABLE A.—TRACTIVE POWER OF WINDING DRUMS.

| Coefficient of friction, $= f$. | First Drum Driven. | | | | Both Drums Driven. | | | |
|---|---|---|---|---|---|---|---|---|
| | Four grooves. | | Five grooves. | | Four grooves. | | Five grooves. | |
| | Tractive power $= P' - p$. | Stress on outgoing cable $= p$. | Tractive power $= P' - p$. | Stress on outgoing cable $= p$. | Tractive power $= P' - p$. | Stress on outgoing cable $= p$. | Tractive power $= P' - p$. | Stress on outgoing cable. $= p$. |
| 0.1 | 0.667 | 0.333 | 0.715 | 0.285 | 0.889 | 0.111 | 0.919 | 0.081 |
| 0.15 | 0.808 | 0.192 | 0.848 | 0.152 | 0.963 | 0.037 | 0.977 | 0.023 |
| 0.2 | 0.889 | 0.111 | 0.919 | 0.081 | 0.988 | 0.012 | 0.993 | 0.007 |

and the quantities deducted therefrom, given in the Table, however apply to a perfectly flexible cable of invariable length, whatever the stress to which it is subjected. In practice neither of these conditions obtain, and though probably the values stated of the tractive power and of the stress on the outgoing cable are nearly correct, the stresses on the intermediate lines between the drums must differ considerably from values therefor determined by the formula.

TABLE VII.—REVOLUTIONS OF DRIVING DRUM AND HAUL OF CABLE.

| From | Revolutions of the Driving Drum. | | | | | Miles the Cable was Hauled. | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1883-84 | 1884-85 | 1885-86 | 1886-87 | 1887-88 | 1883-84 | 1884-85 | 1885-86 | 1886-87 | 1887-88 |
| Sept. 23 to Nov. 1..... | 905 820 | ..... | ..... | ..... | ..... | 6 468 | .... | .... | .... | .... |
| Oct. 30 to May 1 ..... | 4 870 680 | 5 038 620 | 5 007 790 | 5 070 130 | 4 794 160 | 34 776 | 36 333 | 35 755 | 36 201 | 35 515 |
| April 30 to Nov. 1..... | 5 274 350 | 5 217 340 | 5 156 010 | 5 150 390 | ..... | 37 659 | 37 252 | 36 814 | 36 774 | .... |
| Totals to May 1, 1888..... | 46 715 290 | | | | | 333 547 | | | | |

TABLE VIII.—WEAR OF GROOVES IN THE DRUMS.

| When measured. | Apr. 21, 1886. | Apr. 23, 1886. | May 5, 1887. | May 6, 1887. | Feb. 1, 1888. | Feb. 2, 1888. |
|---|---|---|---|---|---|---|
| Drum. | Driving | Driven | Driving | Driven | Driving | Driven |
| | Inch. | Inch. | Inch. | Inch. | Inch. | Inch. |
| Depth of first groove ..... | 0 24 | 0.16 | 0 33 | 0.27 | 0.41 | 0.38 |
| second groove..... | 0.26 | 0 21 | 0.37 | 0.34 | 0.43 | 0.39 |
| third groove..... | 0.23 | 0 2 | 0.38 | 0.34 | 0.41 | 0.39 |
| fourth groove..... | 0 22 | 0.21 | 0 35 | 0.33 | 0.35 | 0.38 |
| Mean depths of the four grooves..... | 0.2375 | 0.195 | 0 3575 | 0.32 | 0.4 | 0.385 |
| Total number of miles the cable had been hauled when measurement was taken ..... | 186 422 | 186 831 | 262 261 | 262 463 | 316 310 | 316 511 |
| Resulting mean diameter of drum, inches..... | 143.525 | 143.61 | 143.285 | 143.36 | 143.2 | 143.23 |
| Comparative number of revolutions made to haul the same length of cable without slip*..... | 1 690 | 1 689 | 1 912 | 1 911 | 4 774 | 4 773 |
| Per cents..... | 100 | 99.9408 | 100 | 99.9477 | 100 | 99.979 |
| Total wear in cubic inches: for each drum when measurement was taken..... | 638.32 | 524.25 | 960.03 | 859.55 | 1 074.18 | 1 033.67 |
| for each drum per mile of cable hauled..... | 0.003424 | 0.002806 | 0.00366 | 0.003275 | 0.003396 | 0.003266 |
| for both drums when measurement was taken..... | 1162.57 | | 1 819.58 | | 2107.85 | |
| for both drums per mile of cable hauled..... | 0.00623 | | 0.006935 | | 0.006662 | |

* For, this let $D$ and $d$ be the diameters, $N$ and $n$ the number of revolutions, of the driving and driven drums, respectively; then when the driven drum has lost one revolution;

$$N - 1 = n, \text{ and } DN = dn; \text{ whence } N = \frac{d}{d - D}.$$

It will seen that this wear was not uniform; the first cable when removed November 7, 1886, was reduced in diameter to $1\frac{7}{8}$ inches, and the grooves it had deepened were barely wide enough to receive the new cable, which for a time wore mainly on the sides and not on the bottom of the grooves. Up to February 1, 1888, the total wear of the grooves in both drums was $\frac{3}{4}$ cubic inches for each 100 miles the cable was hauled; that is, one cubic inch of solid cast-iron was cut from the grooves and ground to powder each 15 hours the plant was running.

23d.—Slip of the Drums.—If the cable did not increase in length under stress, the two drums would revolve inversely in proportion to their diameters; in practice, however, it is quite different: the driven drum lagging behind the other, in a ratio increasing with the loads imposed. A counter being attached to each drum, these results were obtained (Table IX), from which it appears that this slip in June, 1887, was nearly twice so great as in November, 1883; although probably, the drums were more nearly equal in diameter at the later than at the earlier date.

TABLE IX.—SLIP OF DRUMS.

| Date of Observation. | November 18 to 21, 1883. | | April 20 to 23, 1886. | | June 22 to 24, 1887. | |
|---|---|---|---|---|---|---|
| Drum. | Driving. | Driven. | Driving. | Driven. | Driving. | Driven. |
| Revolutions in the same time | 1 567 | 1 566 | 1 090 | 1 089 | 804 | 803 |
| Per cents | 100. | 99 9361 | 100. | 99.9083 | 100. | 99.8756 |

24th.—Creeping of the Cable on the Drums.—A little consideration will show that necessarily, the cable must, as it passes from groove to groove around these winding drums, creep more or less in each groove; to this action the wear of the grooves and largely of the cable is due. If the incoming and outgoing lines were equally strained, or resisted stress without change in length, the cable could not creep unless the grooves in a drum were of unequal diameter. Rarely however, do either of these conditions obtain. The stresses on the two lines range; for the incoming cable from that caused by the maximum haul and the tension car together when the load is greatest and positive, to that caused by the tension car alone when the load is least and negative; and similarly for the outgoing cable from that caused by the tension car alone to that caused by it together with the negative load which sometimes exceeds 75 per cent. of the positive load. The cable extends or contracts in length as the loads imposed increase or diminish, and such changes corresponding in extent to the differences in stresses on the incoming and outgoing lines, must take place in the cable on the drums between the points where the

wrapping begins and ends. Hence, as the grooves in a drum revolve together, the cable in two of them will creep in one and in the other two in the contrary direction; the slip of the driven drum will be determined by the mean of these movements and the difference, if any, between the diameters of the two drums. The resulting wear will therefore be nearly alike for the grooves of either drum and somewhat the greater for those in the driving drum.

25th.—Breakage of Drums.—The drums were made each with flat double arms and two hubs which with the rim were in one piece, as shown in Plate V; in casting, the hubs were split radially into three parts; in finishing, wedges were driven into the spaces so formed and wrought iron bands shrunk on. It was first intended to drive both of the larger drums by means of the smaller friction drum in contact between them and keyed to the main shaft; it was thought that sufficient pressure to develop the necessary tangential friction would be induced by the tension on the several lines of wrapped cable, and if need be, this pressure was to be increased by forcing keys in between the pillow-blocks of the larger drums and the frame. Before, however, this part of the plant was finished, the pinion keyed to the main shaft and the gear wheel bolted to one or the driving drum, were added (see Plate II); and the friction drum was left free to revolve independently of the main shaft, between the two other drums and aid in driving the one without a gear wheel. As so arranged, the plant for a time was operated; soon, however, arms of the smaller and then of one of the larger drums, one after the other, cracked, each quite close to the rim and separated from it. January 25, 1884, several arms of the large drum, all of the arms on one side and most on the other side of the smaller drum, had so failed and been reinforced by segmental iron plates bolted to the broken parts and joining them together. Acting upon the suggestion that these breakages were mostly due to the deforming stresses which, as the drums revolved, constantly tended to diminish the horizontal and increase the vertical diameters; the larger drums were then wedged apart about ¾ inch, whereby the smaller drum was relieved from pressure and consequently from work; the winding drums ran more smoothly than before, the slip apparently did not increase and no other arms failed. Since the friction drum was thus relieved, the winding drums as repaired have been continuously operated and are still in use; the only stoppages being during the past year to renew one of the wrought iron hub bands on the driving drum twice, and one on the driven drum once; these were put on, in halves with bolts, without much delay.

26th.—The new Drums.—In preparation for a possible ultimate failure, duplicate drums were early provided, shown in Plate VI, and have since been kept in reserve. In these the arms are hollow and of an elliptical section; they and the hub on one side were cast in one piece, the rim in another, the bearing surfaces were finished, and the three

parts which collectively form a drum, were bolted together with finished bolts driven into reamed holes.

27th.—Wear of the Engines, Clutches and Gears.—Taking into consideration the irregular and constant work demanded of them, the driving engines have served well; the work has been quite equally divided between the two; as arranged but one can be operated at a time, and to change from one to the other, the plant must be stopped. The jaw clutches, shown in Plate III, whereby they are connected with the drums, have worn greatly. These are of the ordinary form, with two projections on each side; the outer diameter of the bearing surfaces is 26 inches and the mean inner diameter 16½ inches, the depth of jaw is 4 inches; whence the total area of bearing surfaces is 38 square inches; these have worn away about $1\frac{3}{16}$ inches, thus 45⅛ cubic inches of solid metal have been removed from each or 90¼ cubic inches from both clutches during the time they have been in use. The gear teeth are of the epicycloidal form; they were cut accurately to shape. The bearing surface of each tooth is 12 inches wide and 6.4 inches long, or 76.8 square inches; a recent careful examination failed to show perceptible wear.

28th. Description of the Cable.—The specification for the hauling cables used on the Bridge Railway requires, that each cable shall have 6 strands of 19 wires, laid up under a strain of not less than 10 000 pounds, in a regular right hand lay of medium length and around a core of the best hemp rope, well tarred; it shall be 1½ inches in diameter, weigh 3.1 pounds per foot in length,* and withstand a stress of 50 tons; the wires of which the cable is composed shall be of "steel of a uniform and suitable quality;" they shall be about $\frac{1}{10}$ inch in diameter and withstand a stress of 1 000 pounds each; specimens under tensile strain shall, if 12 inches long, stretch not less than 4 per cent., and if 60 inches long, not less than 3½ per cent; they shall also be capable of being wound around a rod ¼ inch in diameter and straightened again without fracture; the ends of abutting wires shall be joined well together with brass solder, and no strands shall be spliced.

Upon examination it is found: the diameter of the cable being 1½ inches, that of each strand is ½ inch, and consequently of the center of the strands is 1 inch; the strands are so laid that they make one revolution around the cable in 8¾ inches, and the wires similarly around a strand in 3 inches, each of cable length. Therefore the ratio of the length of the cable to the length of a strand and of its central wire is 1.0624; to the 6 inner wires of a strand is 1.0855, and to the 12 outer wires is 1.1984; the mean of these ratios for a single wire is 1.1556.†

* The first cable, as made and delivered, weighed 3¼ pounds per foot in length.

† In computation, the extension within elastic limits of one of these cables, under tensile strain, has been taken empirically for the whole cable at 0.000 000 07 per pound of stress per foot in length.

29th.—Strength of the Cable.—The record is not at hand of tests of wires for the first cable which was worn out, and for the second cable which is now in use; that of tests of wires for the third and fourth cables, now in reserve, is given in Table X. The specimens were taken from coils selected at random from the stock prepared, three being cut from each coil so selected; two of these were subjected to tensile strain and the third was wound around a rod ¼ inch in diameter. The last test in each case was satisfactory, the specimen being coiled several turns and then straightened; it was also bent back and forth many times without fracture.

TABLE X.—TESTS OF STEEL WIRE UNDER TENSILE STRAIN.

| Cable and date. | Number given to coil of wire tested. | Diameter of wire, inches. | Length of specimen, inches. | Breaking strain. | | Elongation. Per cent. of length. | Length of specimen, inches. | Breaking strain. | | Elongation. Per cent of length. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Per specimen, pounds. | Per square inch, pounds. | | | Per specimen, pounds. | Per square inch, pounds. | |
| Third cable, January 4, 1887. | 1 | 0.095 | 60 | 1 390 | 193 400 | 4.8 | 12 | 1 220 | 169 700 | 7. |
| | 2 | " | " | 1 210 | 168 300 | 5.8 | " | 1 403 | 195 900 | 5. |
| | 3 | " | " | 1 230 | 171 100 | 3.2 | " | 1 236 | 172 000 | 7.3 |
| | 4 | " | " | 1 070 | 148 900 | ... | " | 1 128 | 156 900 | 9. |
| | 5 | " | " | 1 160 | 161 400 | 5. | " | 1 214 | 168 900 | 8. |
| | 6 | " | " | 1 086 | 151 100 | 4.1 | " | 1 132 | 157 500 | 9. |
| | 7 | " | " | .... | ..... | ... | " | 1 040 | 144 700 | 10. |
| | 7 | " | " | 1 112 | 154 700 | 5. | " | 1 160 | 161 400 | 8. |
| Fourth cable, September 14, 1887. | 1 | 0.095 | 61 | 1 084 | 152 900 | 4.5 | 12 | 1 012 | 142 800 | 6.3 |
| | 2 | 0.099 | " | 1 114 | 144 700 | 6.7 | " | 1 134 | 147 300 | 7.1 |
| | 3 | 0.101 | " | 1 152 | 143 800 | 6.1 | " | 1 140 | 142 300 | 5. |
| | 4 | 0.098 | " | 1 020 | 135 200 | 5.3 | " | 984 | 130 500 | 6.1 |
| | 5 | 0.101 | " | 1 210 | 151 000 | 4.9 | " | 1 280 | 159 800 | 7.5 |

To determine the loss in strength of the first cable, after it was removed, three pieces 23 feet long were put under tensile strain; they resisted up to 69 240, 68 060 and 68 049 pounds respectively, and the two last named stretched about 3½ per cent.

30th.—Stretch of Cables.—During the period a hauling cable is used, it permanently stretches, at first rapidly and afterwards at a lesser rate and quite uniformly. Since March, 1883, a daily record has been kept of the position of the Brooklyn tension car. From this and earlier data, the stretch of these cables is readily deduced, and is here given.

TABLE XI.—STRETCH OF CABLES.

| Cable. | Length of cable hauled, miles. | Stretch. For total length hauled, feet. | Stretch. For last 25 000 miles hauled, feet. | Stretch. Per mile of total length hauled, inches. | Stretch. Per mile of last 25 000 miles hauled, inches. | Cable. | Length of cable hauled, miles. | Stretch. For total length hauled, feet. | Stretch. For last 25 000 miles hauled, feet. | Stretch. Per mile of total length hauled, inches. | Stretch. Per mile of last 25 000 miles hauled, inches. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| First..... | 25 000 | 67. | 67. | 0.032 | 0.032 | First..... | 225 000 | 263.5 | 23.3 | 0.014 | 0.011 |
| " ..... | 50 000 | 109. | 42. | 0.026 | 0.02 | " ..... | 226 283 | 267.8 | .... | 0.014 | .... |
| " ..... | 75 000 | 127.3 | 18.3 | 0.02 | 0.009 | | | | | | |
| " ..... | 100 000 | 150.6 | 23.3 | 0.018 | 0.011 | Second... | 25 000 | 136. | 136. | 0.065 | 0.065 |
| " ..... | 125 000 | 176.5 | 25.9 | 0.017 | 0.013 | " ... | 50 000 | 172. | 36. | 0.041 | 0.018 |
| " ..... | 150 000 | 192.5 | 16. | 0.015 | 0.007 | " ... | 75 000 | 210.7 | 38.7 | 0.034 | 0.018 |
| " ..... | 175 000 | 216.7 | 24.2 | 0.015 | 0.012 | " ... | 100 000 | 250.7 | 40. | 0.03 | 0.019 |
| " ..... | 200 000 | 240.2 | 23.5 | 0.014 | 0.011 | " ... | 107 274 | 287. | .... | 0.032 | .... |

When taut and the tension car is at its highest position, the cable is about 11 400 feet long; whence the first cable during its entire use stretched 2.35 per cent., and the second cable, up to May, 1888, stretched 2.52 per cent. During each 8 hours of the first 40, after the second cable was put in, it stretched $16\frac{1}{2}$, $3\frac{3}{4}$, $6\frac{1}{3}$, $2\frac{1}{2}$ and $1\frac{3}{4}$ feet respectively, or altogether $30\frac{3}{4}$ feet; some of this doubtless was slack, not all taken out when the splicing was done. The stretch of a cable is due partly to the tension to which it is subjected, but doubtless much more to the action of the grips. As indicating the probable effect of their pressure on it, (see Article 37); referring to Table I, the grips were applied 1 074 times for the 329 trains run April 29, 1884; 2 150 times for the 515 trains run April 27, 1886; and 2 688 times for the 487 trains run May 1, 1888. Taking, (Article 20), 107 feet as the mean length of cable which passes be-

tween the grip sheaves, from the time the grip is closed until the train moves at full speed; on the days mentioned, the total length of cable thus subjected to pressure, was 114 918 feet, 230 050 feet and 287 616 feet; and if the compressed spaces were uniformly distributed, the whole cable passed between the grip sheaves, 10, 20 and 25 times respectively. As the cable stretches, the hempen core becomes harder, more compact and of course, smaller; from this, as well as wear, the cable also is reduced in size; the first, when taken out, being but $1\frac{1}{4}$ inches, and the one in use now is about $1\frac{5}{16}$ inches in diameter. Besides stretching permanently, the cable under changes of load and variations in temperature, extends or contracts within elastic limits, sometimes to a noticeable extent; data however, are lacking to determine with precision how much is this movement, separate from the other.

31st.—Renewing the Cable; Splicing.—The first cable was in continuous use from the opening of the Railway, to November 7, 1886; then it was replaced by the second cable, which is still serviceable. When a cable is put in place, its ends are spliced; it is respliced when the length of slack allows the Brooklyn tension car to reach its lowest position and then the cable is shortened; also when the wires at the splice are much worn, or many of them are broken, the defective part is cut out and a piece of new cable, of diameter the same as that of the worn cable, is inserted; in which case, two splices are necessary. During its use, the first cable was respliced seven times, twice with a single splice and five times with two splices; the second cable has been respliced four times, thrice with a single splice and once with two splices. The length of these splices varied; that of the second splice in the first cable was 96 feet, and that of those lately made is 60 feet; the shorter splice is found to be as serviceable as the others, and when resplicing is to be done, it is more likely to permit the old splice to be cut out. If a splice, say 60 feet long, were separated without disturbing the lay of the strands, leaving the lapped ends of the cable, side by side, as they were in the splice; it would be seen that for either cable end, the strand ends were one-sixth a splice length or 10 feet apart, except at the centre where they would be one-third a splice length or 20 feet apart; also—designating the cable ends by *A* and *B;* that the strands of *A* lapped by the corresponding strands of *B*, in pairs, each 2 feet. In making a splice, taking the strands in numerical order from the longest to the shortest, the first strand of *A* is wound into the place left by the shortened end of the sixth strand of *B;* the second strand of *A* into that of the fifth strand of *B;* and similarly for the other pairs of strands. Where the pair of strands, which are in one line, lap by each other; the cable is untwisted, 2 feet of the hempen central strand is cut out, and in place of the piece so removed, the free strand ends are tucked in. Thus the diameter of the cable at the splice is the same as elsewhere; except at the six points where the strand ends cross each other and are turned into

the central space; here the diameter is slightly increased. The cable to be spliced being on the sheaves and pulleys, hauled taut, and made fast, with the ends lapping by each other and left free, the splicing is done as follows: the strands at each end are unwound back to the centre of the splice; the two ends are brought closely together and wrapped, with the unwound strands of *A* interposed regularly between the unwound strands of *B;* then the sixth strand of *A* is cut close to the wrapping, unwound, and into the spiral space so left, the first strand of *B* is at the same time wound; not more than a single turn being permitted between the two strands; similarly the other strands are wound in. As the replaced strand sinks into the spiral space, it is seated by gentle blows from a copper hammer; and to untwist the cable, in tucking in the free ends of the strands, it is held in a strong, round jawed vise. Before splicing, the slack is taken out and the cable made taut by a tackle, to which a locomotive is attached. A foreman with a gang of eight men, will now make one of these splices, after the cable is in position and secured, in from two to three hours. The whole operation is usually done in the interval between the regular stopping of the cable, at 1 o'clock A.M., and starting it again at 5 o'clock A.M.

32d.—Wear of Cables.—By the constant bending of the cable around the sheaves and drums, where there must be a slight movement of the strands and wires over each other and particularly at the splices where the ends of the strands lap by, the inner projecting surfaces in contact are abraded and wires from time to time broken. Also somewhat by the action of the grip sheaves, but more by contact with the grooves in the sheaves and by the slip in the grooves of the drums, the outer surface of the exterior wires are worn away. An experimental grip, with revolving, solid metal jaws, was tried on one car, for a few trips, early in 1884; shortly afterward wires were found nearly or quite pinched off, being imbedded where they crossed as if sunken under a heavy hammer, and in one instance, 200 broken wires in 100 feet of cable length were reported. In a hauling cable however, the wires are constantly breaking; so long as the ends do not project and strip, the only injury which results, is the decrease in cable strength, and this is slight, if the breakages are evenly distributed and not close together. As may be expected, the wear requiring attention and repair is confined to the splice and its immediate vicinity; this repair, (Article 31), is usually done by inserting a new piece of cable; sometimes however, a short piece of badly worn strand has been replaced by a new one. No cable has been broken, and but once has a strand hauled loose and unwound. The loose end, which was drawn out at the splice, was first noticed near the Brooklyn outgoing sheave, and before the driving engine was stopped, it had passed through New York Station, and about 25 feet were unwound, however without injury to the pulleys and sheaves over which it had gone.

33d.—Cable Service.—The first cable was in use 3 years and 43 days, and the second cable, to May 1, 1888, has been in use 1 year and 176 days. The comparative service rendered by the two cables is shown by Table XII, in which certain items are estimated. By this it will be seen, that as a mean of the work done, over each mile it was hauled, the first cable moved 96.2 tons, and the second cable moved 200.8 tons.

TABLE XII.—CABLE SERVICE.

| Cable. | Loads hauled. | Weights. | Total weights hauled. | Distance hauled. | Total service. |
|---|---|---|---|---|---|
| First cable, used 3.12 years, hauled 225 273 miles. | 257 052 cars. | 8½ tons. | 2 184 992 tons. | ..... | ..... |
| | 408 265 " | 10 " | 4 082 650 " | ..... | ..... |
| | 172 578 " | 16 " | 2 761 248 " | ..... | ..... |
| | 837 895 cars. | ..... | 9 028 890 tons. | $2\frac{1}{16}$ miles. | 18 622 086 ton-miles. |
| | 48 960 000 passengers. | 125 pounds. | 3 060 000 " | $1\frac{1}{32}$ " | 3 155 625 " |
| | Total service..... | ..... | 12 088 890 tons | ..... | 21 777 711 ton-miles. |
| Second cable, in use 1.48 yrs., hauled 107 274 miles. | 15 398 cars. | 8½ tons. | 130 883 tons. | ..... | ..... |
| | 135 911 " | 10 " | 1 359 110 " | ..... | ..... |
| | 476 823 " | 16 " | 7 629 168 " | ..... | ..... |
| | 628 132 cars. | ..... | 9 119 161 tons. | $2\frac{1}{16}$ miles. | 18 808 270 ton-miles. |
| | 42 420 000 " | 125 pounds. | 2 651 250 " | $1\frac{1}{32}$ " | 2 734 100 " |
| | Total service..... | ..... | 11 770 411 tons | ..... | 21 542 370 ton-miles. |

34th.—Tension Car Renewals.—New wheels and axles were put under the Brooklyn tension car, February 21, 1886, in place of the first ones which were much worn; about this time the weight carried by the car was reduced 5 000 pounds, and a nearly equivalent direct weight of 1 100 pounds was attached by a wire rope and pulleys. The New York tension car at first had a single horizontal guide wheel, which ran loose on the sheave pintal and traversed the horizontal track described in Article 8. This failed and July 20, 1886, a pair of guide wheels smaller than the first and having independent journals were substituted; a new horizontal track was then also supplied; these are still in good condition. The sheaves of both cars have also been renewed.

35th.—Wear and Renewal of Sheaves and Pulleys.—Several of the sheaves first put in, made as shown in Plate X, failed by the wedges

driven in the split hub working out and the hub becoming loose on the shaft. Some of these were refitted, greater care being taken in wedging and banding the hub, and have served well since. Others were taken out because of wear in the grooves, and a part were replaced by sheaves made as shown in Plate XI. The wear in the grooves of those now in use was measured May 20, 1888. Table XIII records the renewal and wear of sheaves, arranged in order as the cable moves, beginning at the drums The first Brooklyn tension car sheave became loose in the hub; an arm of the second one, a sheave which had been repaired and was of the same design as the first, cracked near the shaft. Two sheaves have not been renewed; both have been repaired at the hub; the horizontal sheave in New York Station has been repaired twice and is now much worn in the groove as stated in the Table, and in the bore; its pinta; has been revolved so as to bring a fresh surface into bearing, and also is much worn. It will be seen that the New York outgoing sheave deflects the cable the least: and that excepting the two New York incoming sheaves, around six of the others about one-fourth turn and around the Brooklyn tension car sheave one-half turn is made. Around each of the first New York incoming sheaves about one-fourth turn was made as shown in Plate XVII; to increase the tractive power of the new auxiliary cable plant, around these sheaves now in use three-fourths turn was made, as shown in Plate XIX, and retained until a few months ago, when to permit a change in the switching arrangements, the cable was shifted to its former position.

Taking the wear of the grooves and the time such occurred, given in Table XIII as a basis, the estimated mean wear during the entire operation of the plant, is as follows: one cubic inch of cast iron was cut from the eight sheaves not packed, in 12½ hours; one cubic inch of wood from the two sheaves so packed, in 16¾ hours and one cubic inch of leather and india rubber from the two sheaves so packed in 43⅛ hours; and summing the two (see Article 22), one cubic inch of cast iron was cut from the grooves of the drums and sheaves together in 6¾ hours. The angles of contact between the several sheaves and the cable being considered; it is also estimated that under like conditions, the relative wear of the three styles of grooves will be about as follows: taking a groove packed with leather and india rubber as 10, that of one packed with wood will be 69, and of one not packed will be 25. This attrition is done by the cable, which must also be worn much more by the grooves that are not packed than by the others.

In renewing the sheaves, the diameter of the journals of two was increased from 5 to 6 inches, and of two others from 3 to 4 inches; wherever the pillow blocks were also renewed, those shown in Plate XIV were substituted for those first used, shown in Plate XIII. Before this was done, these journals frequently heated; they have given little trouble since the changes were made.

TABLE XIII.—RENEWAL AND WEAR OF SHEAVES.

| Location of sheave. | Description. | Packing in groove. | Length and diameter of journals, inches. | When sheave was renewed. | Length of service, years. | Wear of groove. | |
|---|---|---|---|---|---|---|---|
| | | | | | | Depth worn in groove, inches. | Length of wear, years. |
| Engine room, low frame.... | Plate X. | None. | 6 x 4 | ..... | .... | .... | .... |
| | Plate X., repaired. | " | " | In use. | .... | 0.22 | .... |
| Engine room, tension car.. | Plate X. | " | 6 x 3 | 1885, May 24. | 1.67 | .... | .... |
| | Plate X., repaired. | " | " | 1886, April 24. | 0.92 | .... | .... |
| | Plate X., repaired. | " | " | In use. | 2.02 | 0.31 | 2.07 |
| Engine room, high frame.. | Plate X. | " | " | " | 4.61 | 0.34 | 4.66 |
| Brooklyn—outgoing ..... | Plate X. | " | " | 1884, June 15. | 0.73 | .... | .... |
| | Plate XI. | " | 6 x 4 | In use. | 3.88 | 0.28 | 3.93 |
| New York — first incoming .... | Plates X, XVII. | Wood. | 6 x 5 | 1885, June 13. | 1.73 | 0.84 | 1.73 |
| | Plates XII, XIX. | Leather and rubber. | 6 x 6 | In use. | 2.88 | 0 44 | 2.93 |
| New York—second incoming | Plates X, XVII. | Wood. | 6 x 5 | 1885, June 13. | 1 73 | 0.5 | 1.73 |
| | Plates XII, XIX. | Leather and rubber. | 6 x 6 | In use. | 2.88 | 0.44 | 2.93 |
| New York—horizontal.... | Plate X. | None. | 4-in. pintal. | " | 4.61 | 0.53 | 4.66 |
| New York—tension car.. | Plate X. | " | " | 1886, June 20. | 2.74 | .... | .... |
| | Plate XI. | " | " | In use. | 1.87 | 0.38 | 1.92 |
| New York—outgoing..... | Plate X. | " | 6 x 3 | 1884, Dec. 8. | 1.2 | .... | .... |
| | Plate XI. | " | 6 x 4 | In use. | 3.41 | 0.31 | 3.46 |
| Brooklyn — incoming .... | Plate X. | " | " | 1884, June 5. | 0.7 | .... | .... |
| | Plate XI. | " | " | In use. | 3.91 | 1.03 | 3.96 |

The pulleys which support the cable between the rails, only have been renewed when the flanges or arms were accidentally broken, which however, has rarely happened; their packings wear quite regularly, the mean service being about ten weeks. A supply of repacked pulleys is kept in stock, and a change is quickly made, by a single workman, whenever necessary and while the cable is running. It was found that the tilting pulley shown in Plate XVI, by the inertia of its weight and other parts to be overcome when it is moved and as each car passes over it, gave quite a blow to the grip frame and tended to force it out of place; the coiled spring recently substituted for the weight (as described, Article 10), attached to the tilting lever so as nearly to balance it and the other parts during the entire movement up and down, has much reduced the concussion; the grip is kept with less care in its position under the car body, and the system of tilting pulleys at a platform is operated with greater ease and certainty.

36th.—Train Equipment.—As heretofore stated, the Railway was first supplied with cars, one-half 36 feet 4 inches long, weighing 8½ tons, and one-half 48 feet long, weighing 10 tons; the shorter cars were sold and others purchased 48 feet 10 inches long, weighing 16⅝ tons. It was soon found inconvenient to make up trains with cars varying much in length; for sufficient capacity the longer cars were required; and that they might endure the continuous service performed, without change in shape or frequent repairs, greater strength and consequently increased weight were requisite; to permit more rapid entrance and egress of the passenger load, side doors were added, and to control more certainly the train in any emergency on the steep grades of the railway, the vacuum brake which was first held in reserve, was fitted for constant use, thereby replacing the hand brake. To increase the effective brake resistance, some cars have been equipped with boxes from which sand may be discharged on the rails; so far, the necessity of such has not been proven. A large part, compared with other railways, of the round trip being over curves of short radii, frogs and switch points; the wheel flanges wear rapidly, and care has to be taken to preserve the gauge.

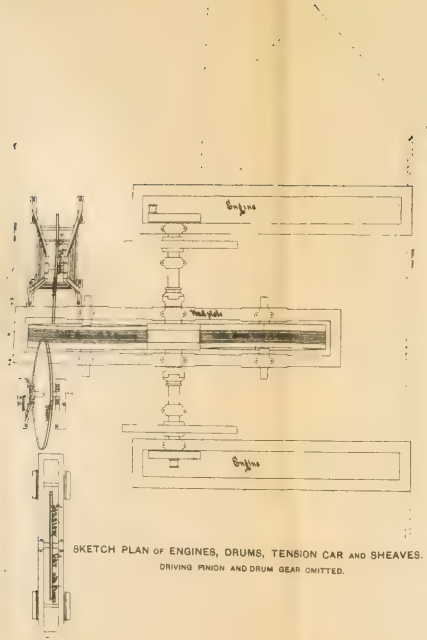
37th.—Grip Service.—By inserting a spring balance in the two lines of wire rope whereby the grip is operated (see Plate XXIV) it was found that the brakeman or gripman could apply over 400 pounds stress at the end of each grip lever. The friction of the sheave against the cable must always be greater than that of the brake against the inner periphery of the sheave, if the same pressure is applied to each, as in this grip; otherwise the cable would slip between the sheaves. The friction of oak against cast iron, both being dry and not lubricated, may be 25 per cent. of the pressure causing it; whence the tractive capacity of the grip will be equal to the pressure applied to each brake and to one-half that exerted by the grip lever. The multiplication by the grip gear

(Plate XXII) is 7.4 and by the grip lever when the grip is closed is 25; hence for 4 000 pounds direct haul, the pressure on each pair of brakes will be 8 000 pounds, and the stress at the outer end of each grip lever, 320 pounds; quite within the limit of working force the gripman may apply at the hand wheel; and much less than is usually exerted. As practically illustrating the power of the grip now used, this record is copied. On the evening of April 18, 1887, the driving engine was nearly stopped in consequence of an omission in the New York Station to uncouple from a three-car train attached to the cable by two grips, the switching locomotive, to the rear of which was coupled another three-car train; whereby the two grips were hauling six cars and a locomotive.

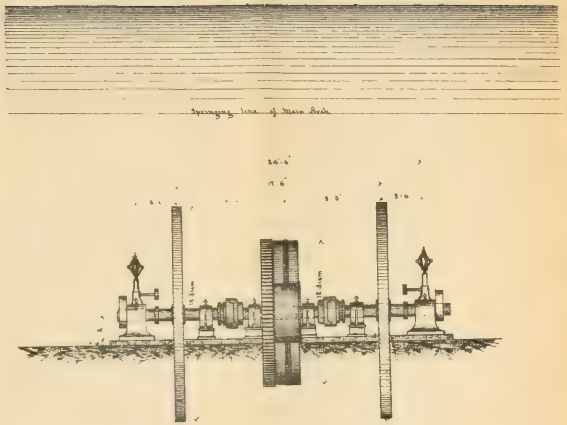
Aside from renewal of the sheave packings, the repairs to the grips are chiefly due to the train when entering a Station, running beyond the incoming sheaves without the cable being released, which sometimes happens. Thus in May, 1885, the forward grip was not opened as the train approached New York Station, and the cable was pulled out, bending the two lower side sheave shafts and slightly tearing the packings; the grip was used on the return to Brooklyn; the damaged shafts with their sheaves were replaced in a few minutes by others, and the car was again put in service. The accident was caused by the brakeman not being able to disengage the grip; probably after it was closed, as the train left Brooklyn Station, the cable splice drew in between the sheaves and strained the grip gear. The sheave packings of the grip first used, rarely served longer than 30 days, without renewal; the grip now used was first put on the Railway, April 2, 1885, and the cars were equipped with it in due course; a record of the service of all sheave packings of these grips is kept; from which it appears that from April 13, 1885, to March 31, 1888, 236 sets were inserted and removed; the term of service ranged from 348 to 37 days, and the round trips made from 9 815 to 962, the average being 4 075 round trips; taking $2\frac{1}{16}$ miles as the length of a round trip, the mileage ranged from 20 244 to 1 984; the average being 8 405 miles.

38th.—Lubrication.—At first, all bearings were lubricated with oil, from an oil can or cup; afterwards for most, was substituted a grease of the consistency of lard and flowing when slightly heated; with this a special cup is employed, having a screw cover which the attendant turns a little at proper intervals, in some cases only once a day, and forces the lubricant between the wearing surfaces. Generally, the grease is thus more conveniently applied than the oil; and so far as known in the absence of definite test, at considerably less cost. The first cable, before it was much worn, was coated with a hot mixture of vegetable tar and linseed oil; the second cable soon after it was put in was brushed with linseed oil; and in either case no other applications were made. How far such are economical is uncertain; a new cable, as delivered, is

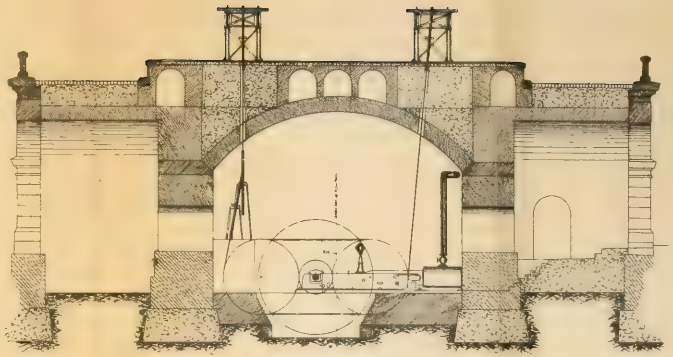
coated with tar, which prevents rusting while it is on the reel and held in reserve; when in use it externally is kept bright by the drums, sheaves and grips, and internally there is no oxidation. Could the wires forming the cable, where they overlap each other and are in contact, be lubricated, some wear at these places might be saved; but the cable is not likely to fail from this wear; any suitable coating will lessen the hold of the grip and the haul of the drums; a corresponding increase of grip pressure will be necessary, thus inducing a much greater destruction of the cable than that sought to be prevented, as well as adding to the wear of the packings of the grip sheaves.




SKETCH PLAN OF ENGINES, DRUMS, TENSION CAR AND SHEAVES.
DRIVING PINION AND DRUM GEAR OMITTED.




SKETCH ELEVATION OF ENGINES AND DRUMS.



CROSS SECTION OF APPROACH,
SHOWING POSITION OF ENGINES AND DRUMS.

PLATE IV.
TRANS. AM. SOC. CIV. ENGNS.
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LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

# DRUMS, TENSION CAR AND SHEAVES.

DRIVING PINION AND DRUM GEAR OMITTED.

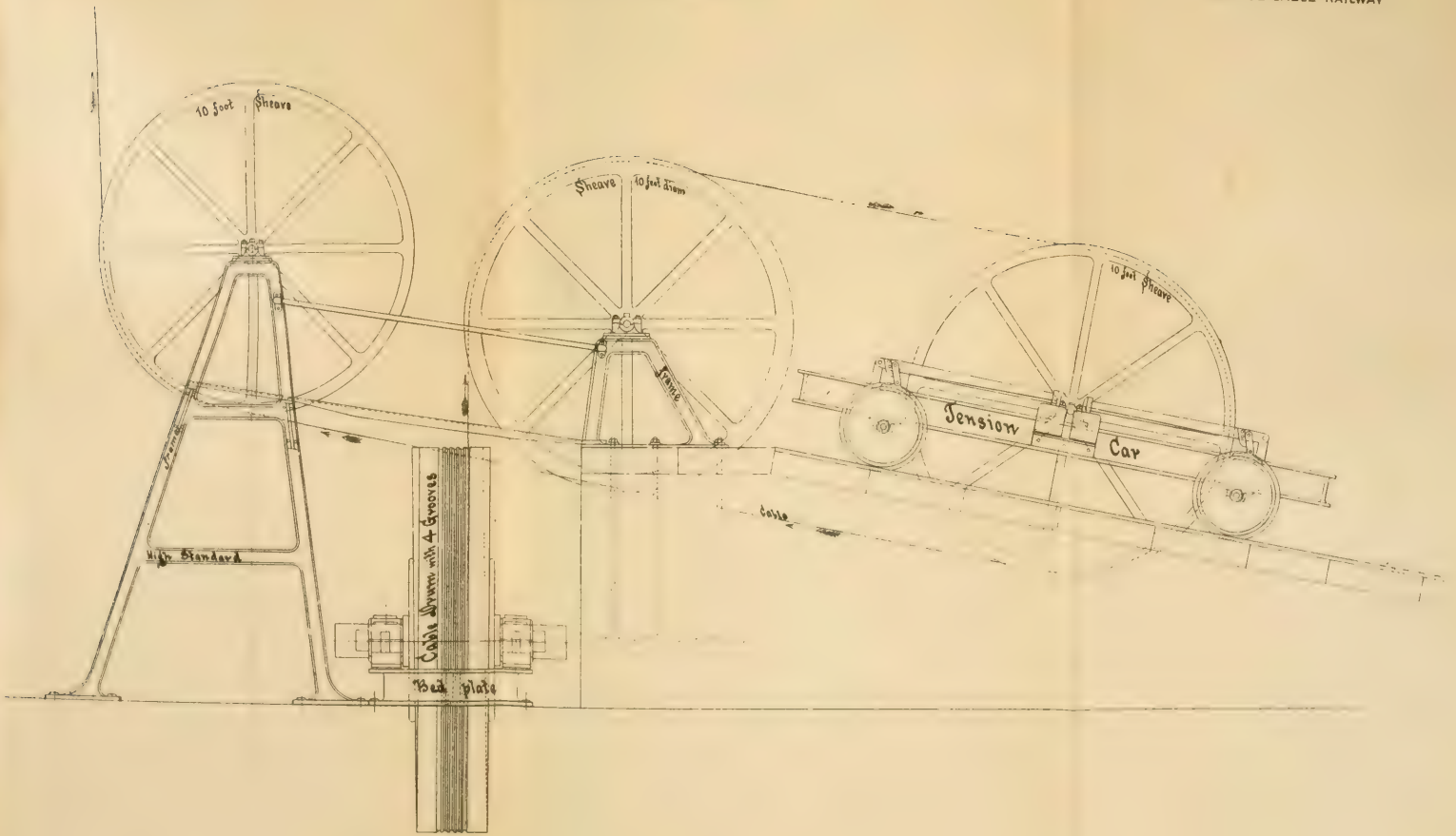
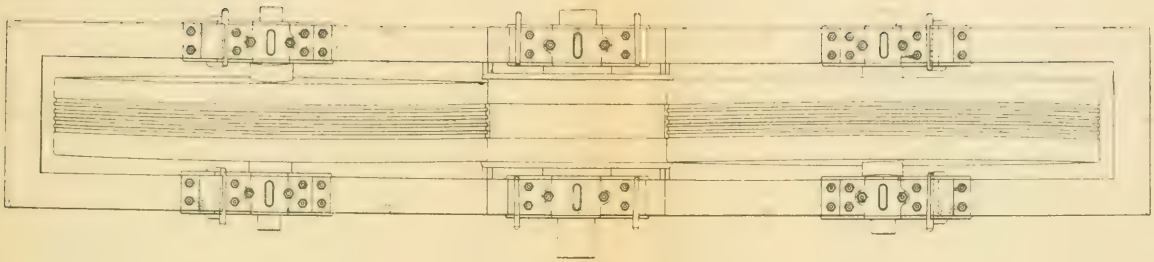
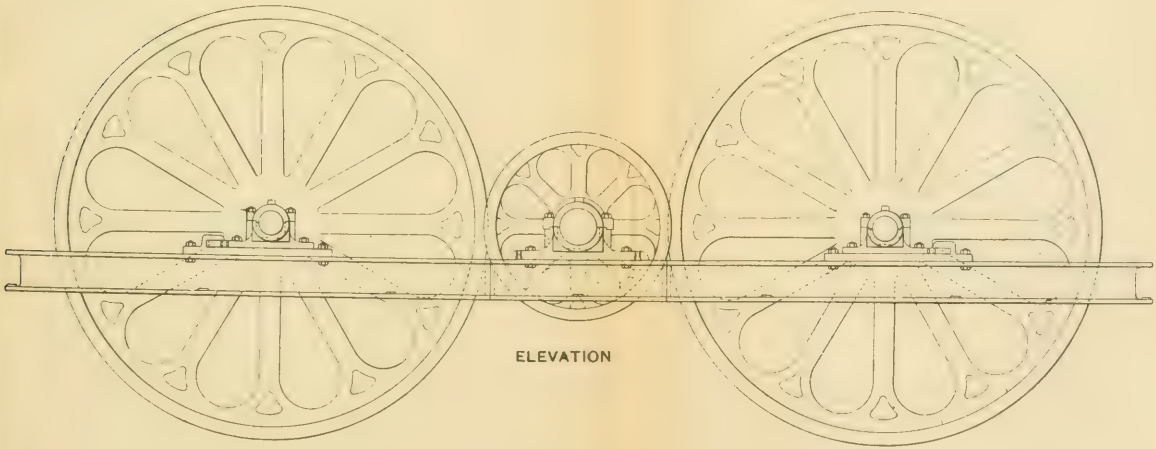


PLATE V
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII Nº 380.
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

DRUMS AND FRAME.
AS FIRST MADE
DRIVING PINION AND DRUM GEAR OMITTED.

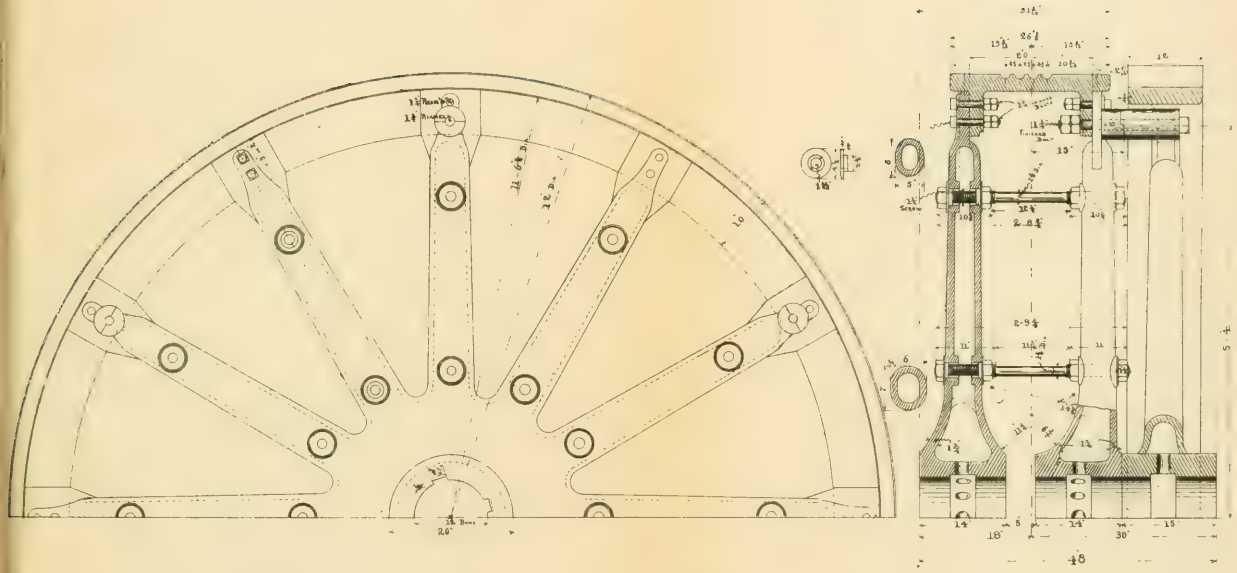


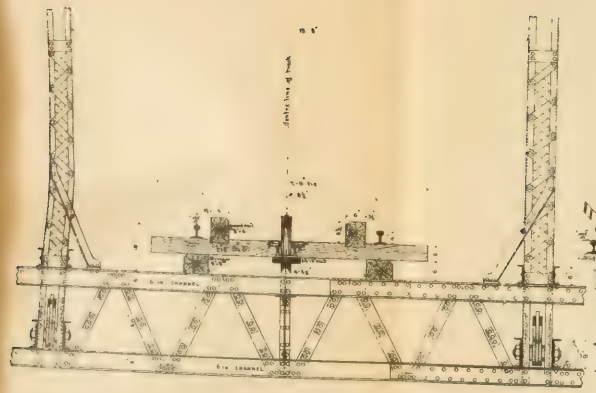
PLAN.



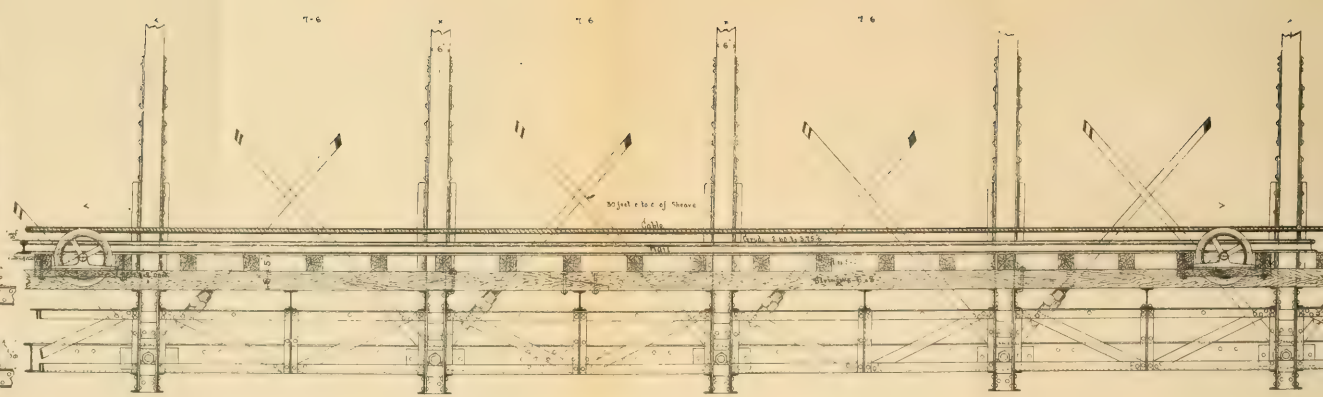
ELEVATION

DRUM AND GEAR WHEEL.
AS AFTERWARD MADE.





CROSS SECTION OF RAILWAY.



LONGITUDINAL SECTION NEAR CENTRE OF TRACK,
5×8 INCH, GUARD-RAIL OMITTED

PLATE VIII
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII. No. 380.
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

# PLAN OF NEW YORK STATION.

SHOWING POSITION OF SHEAVES, CABLES AND TRACKS

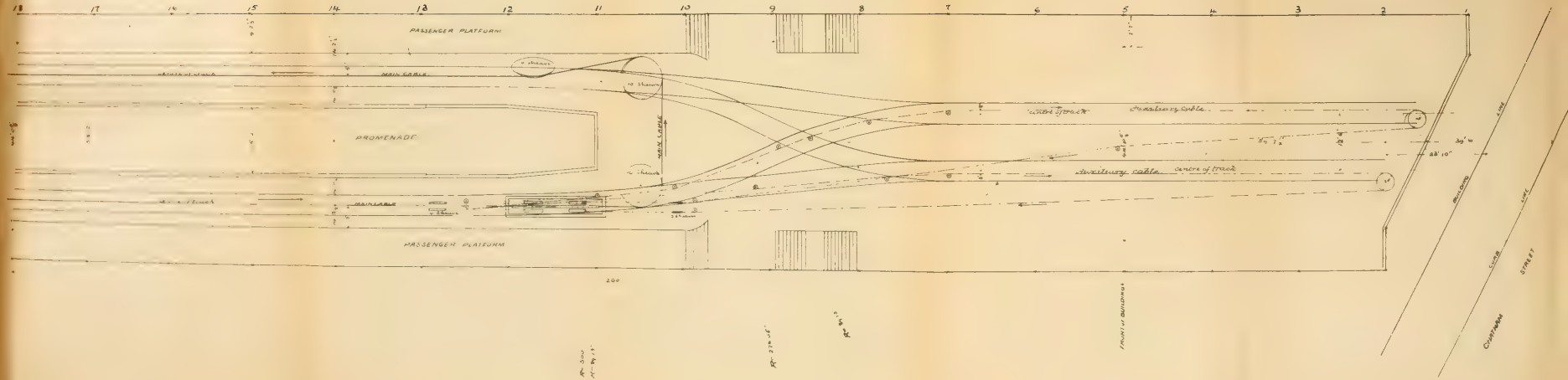
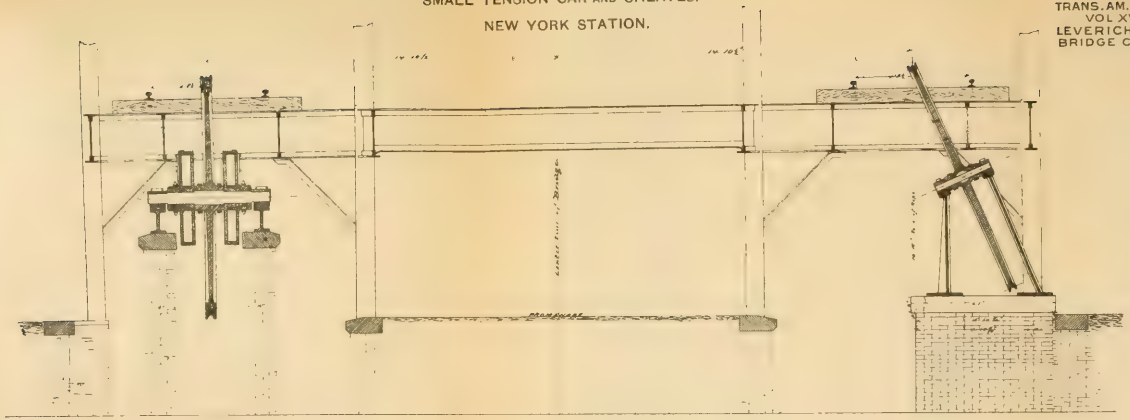
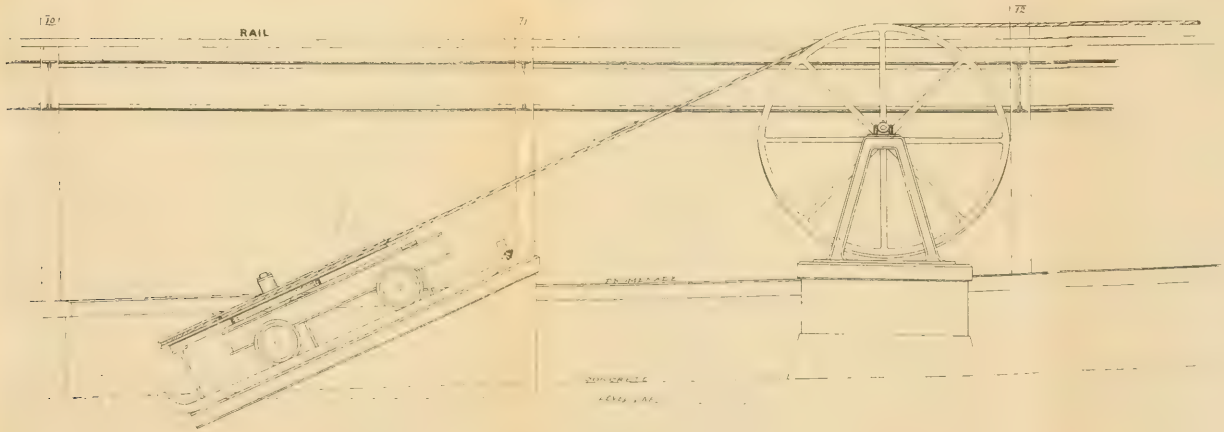


PLATE IX
TRANS. AM. SOC. CIV. ENGNS.
VOL XVIII Nº 380.
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

SMALL TENSION CAR AND SHEAVES.
NEW YORK STATION.



CROSS SECTION OF STATION.




SMALL TENSION CAR AND OUTGOING SHEAVE.

SHEAVES FIRST USED.

GROOVE NOT PACKED.



SECTION ON AB.



SECTION ON E.F.

PLATE X

TRANS. AM. SOC. CIV. ENGNS.
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LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY





SECTION ON CD.

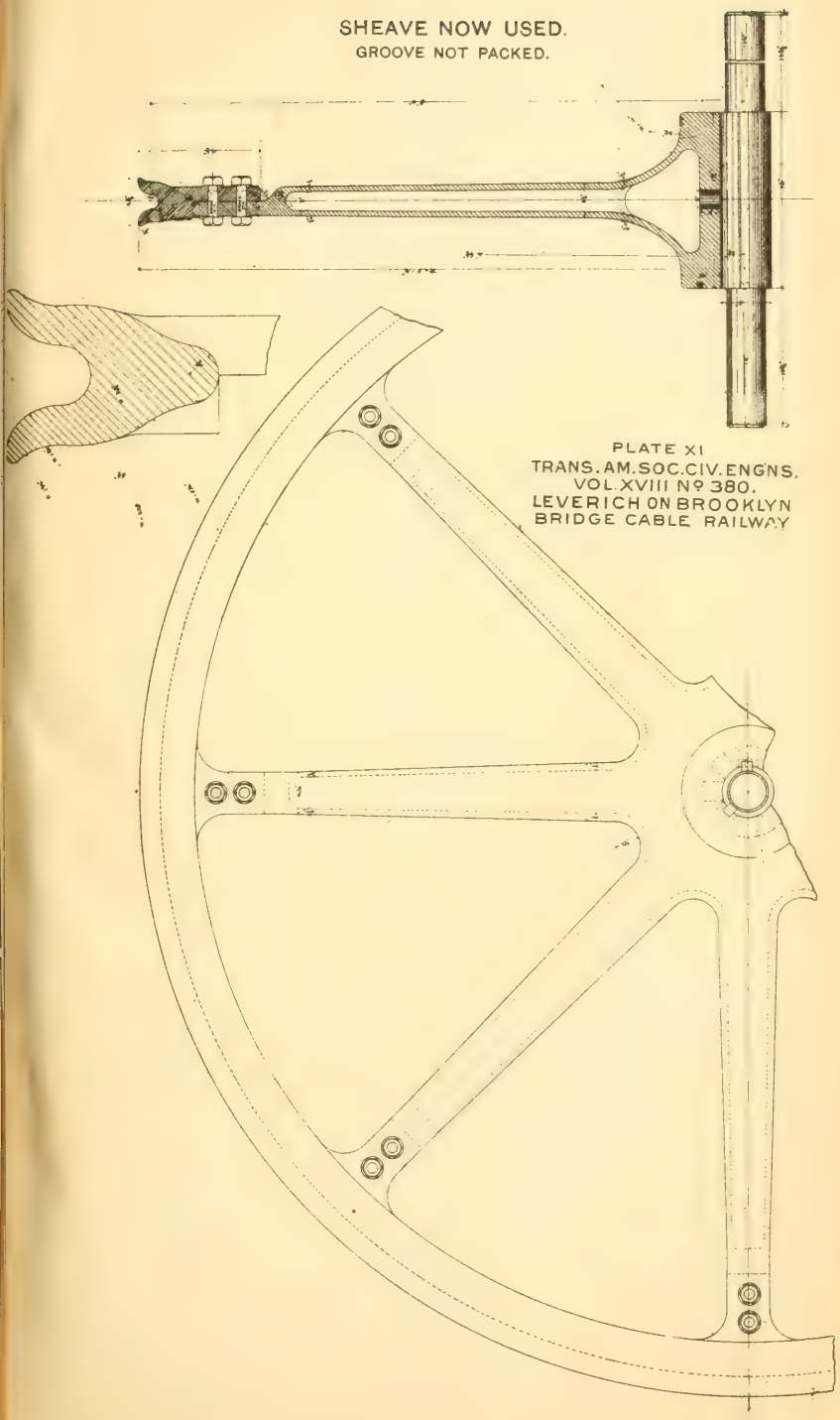


PLATE XI
TRANS. AM. SOC. CIV. ENGNS.
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LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

PLATE XII
TRANS. AM. SOC. CIV. ENGNS.
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LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

SHEAVE NOW USED.
GROOVE PACKED.

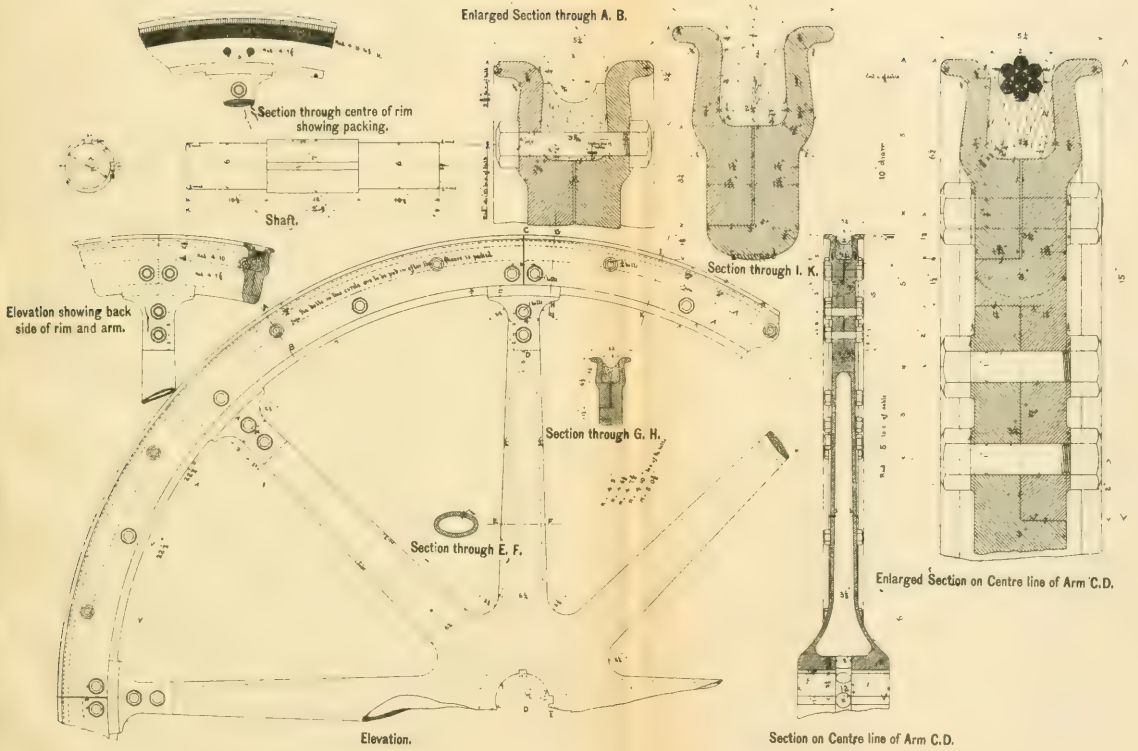
Enlarged Section through A. B.
Section through centre of rim showing packing.
Shaft.
Section through I. K.
Elevation showing back side of rim and arm.
Section through G. H.
Section through E. F.
Enlarged Section on Centre line of Arm C.D.
Elevation.
Section on Centre line of Arm C.D.

PLATE XIII
TRANS. AM. SOC CIV ENGNS
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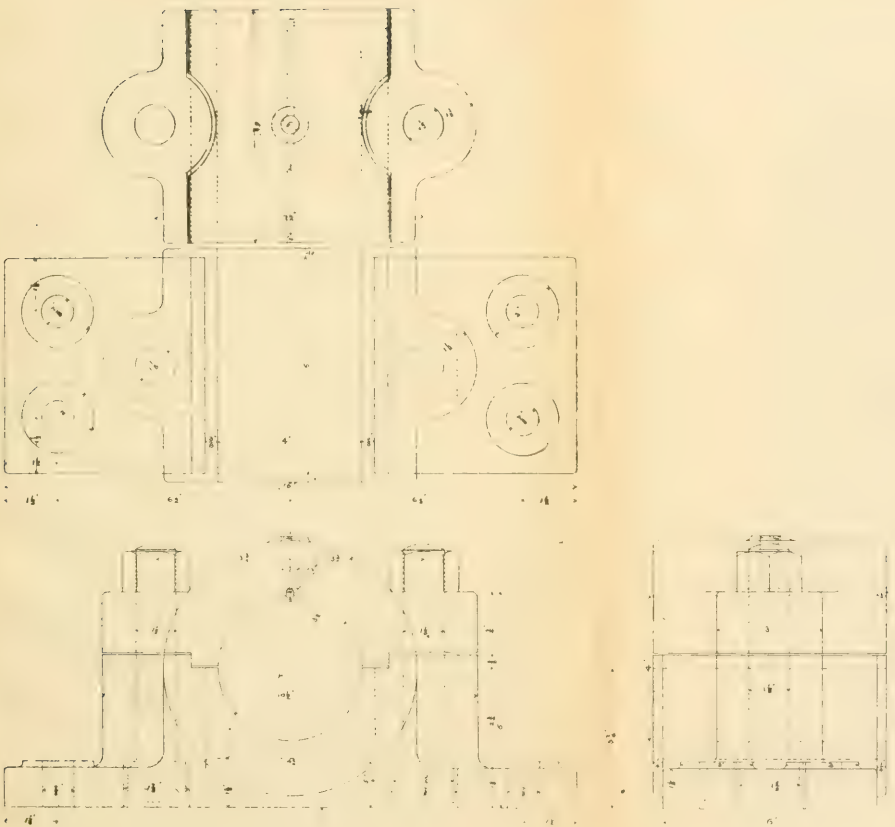
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

## SHEAVE PILLOW BLOCK.

AS FIRST MADE.



SHEAVE PILLOW BLOCK.
AS NOW MADE.

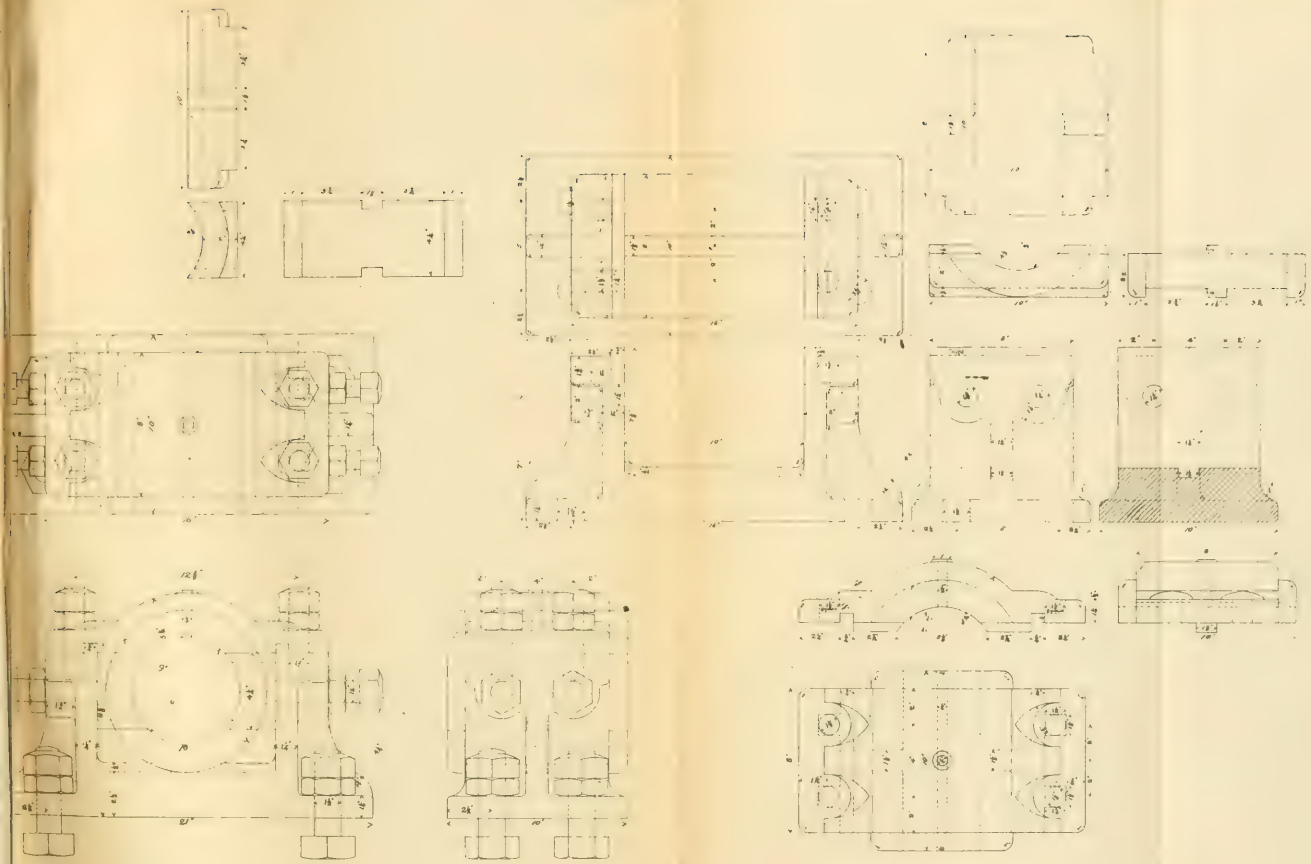


PLATE XV
TRANS. AM. SOC. CIV. ENGNS
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LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

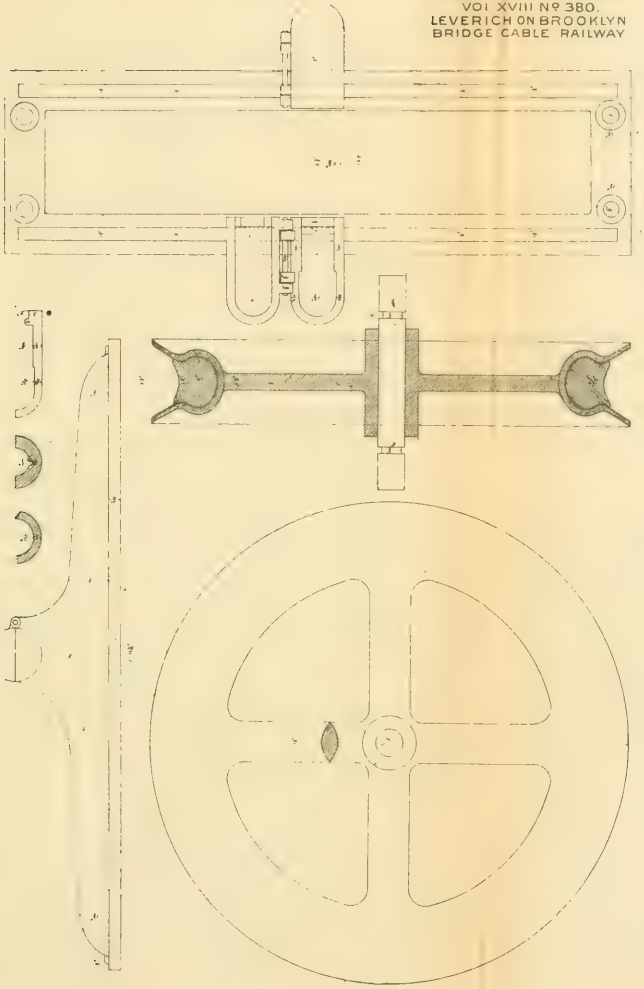

PLATE XVI
TRANS. AM. SOC. CIV. ENG'NS
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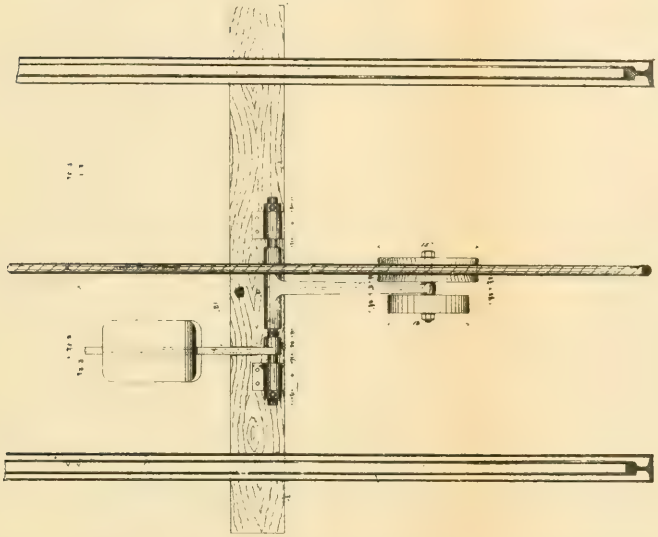
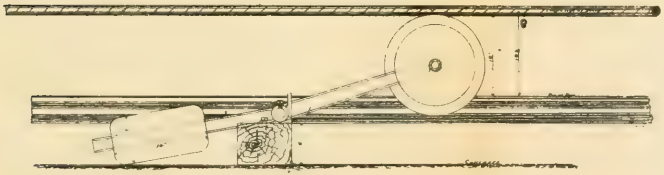
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

TILTING PULLEY.



PLAN.

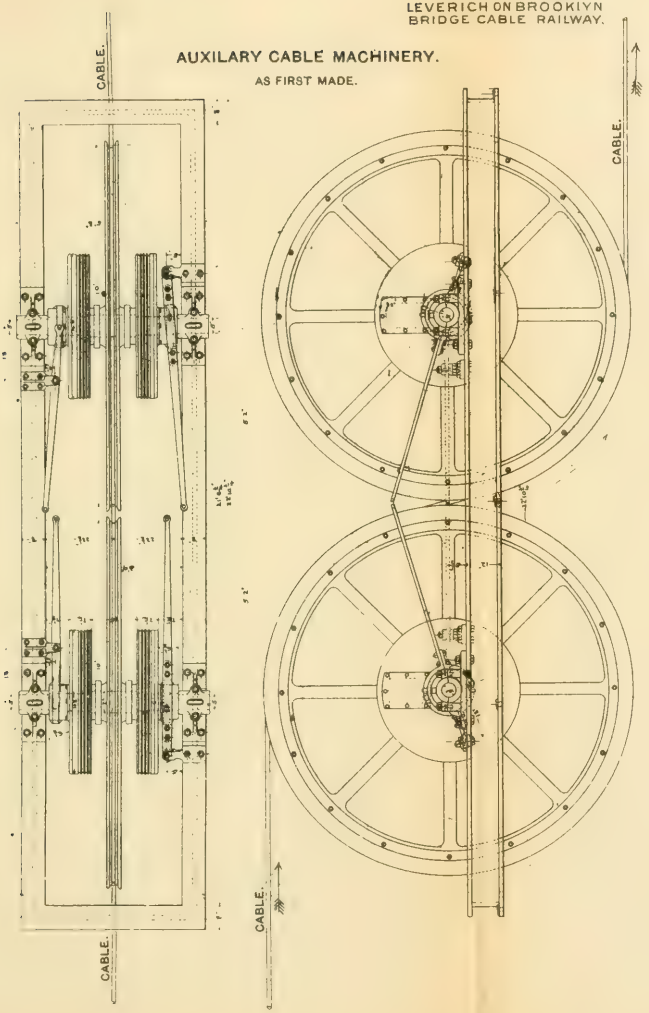


ELEVATION.

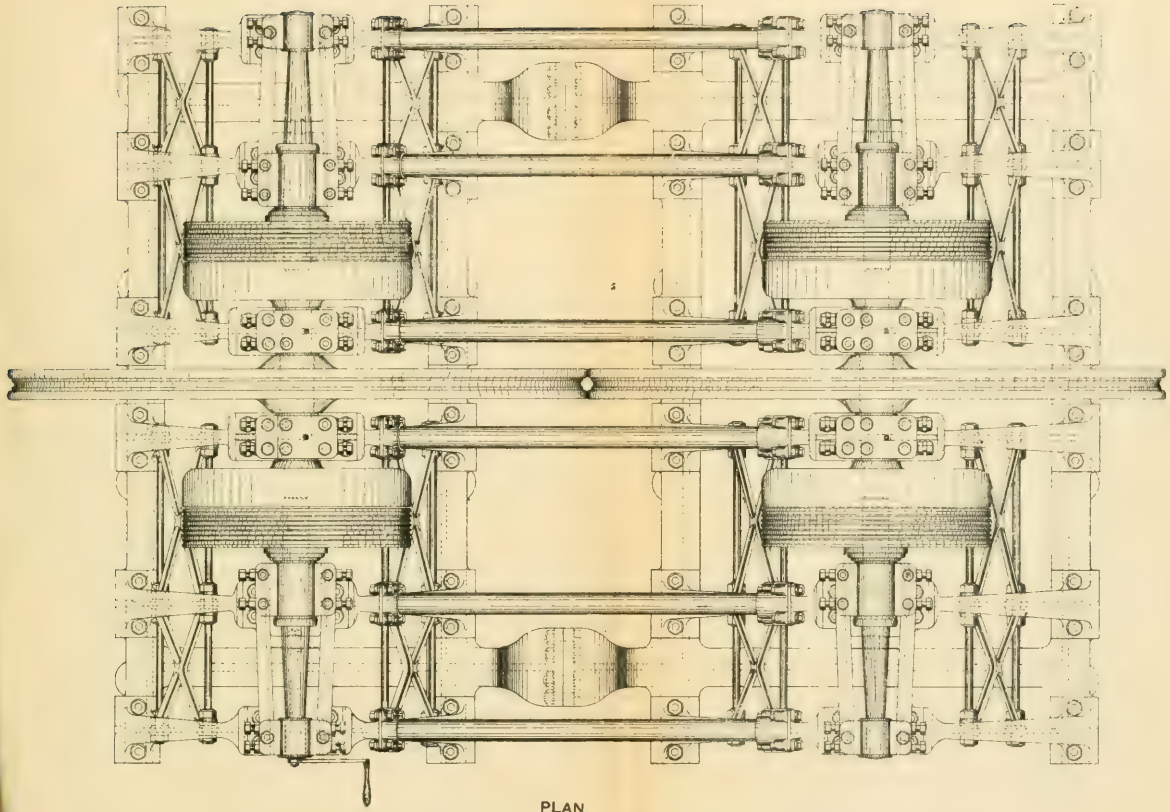
PLATE XVII
TRANS. AM. SOC. CIV. ENGNS
VOL. XVIII Nº 380.
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY.

## AUXILARY CABLE MACHINERY.

AS FIRST MADE.



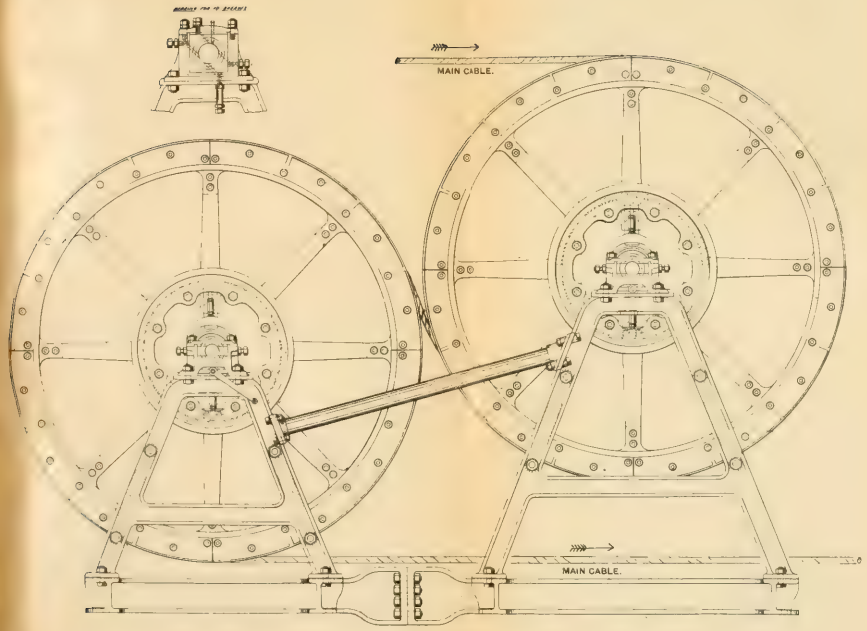
AUXILARY CABLE MACHINERY.
AS AFTERWARD MADE.



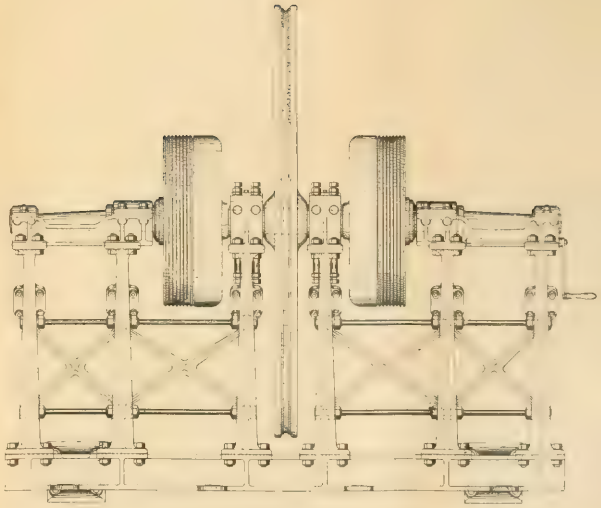
PLAN.

# AUXILIARY CABLE MACHINERY.

AS AFTERWARD MADE.




SIDE ELEVATION.



FRONT ELEVATION.

PLATE XX
TRANS. AM. SOC. CIV. ENGNS
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LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

GRIP AS FIRST USED.

TRIP GEAR.

BOTTOM OF CAR.

SIDE VIEW OF LATCH ARM

END VIEW

PLAN.

END VIEW

SECTION ON C.D.

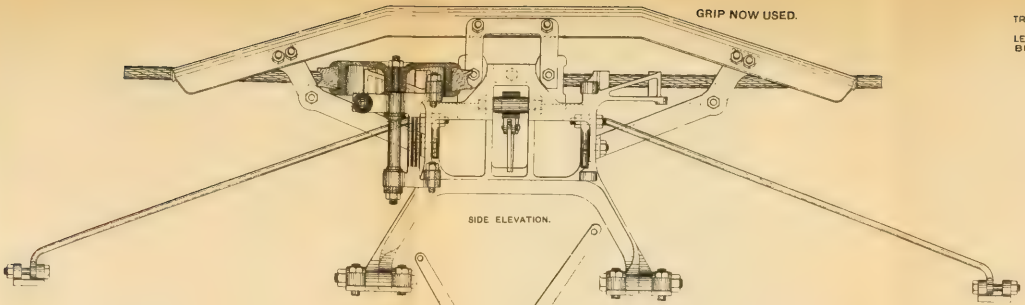
SIDE ELEVATION.

SECTION ON A.B.

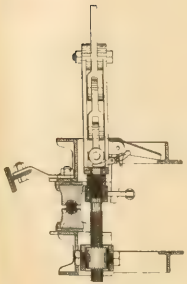
SECTION THROUGH PULLEYS.

SCALE $\frac{2}{25}$.

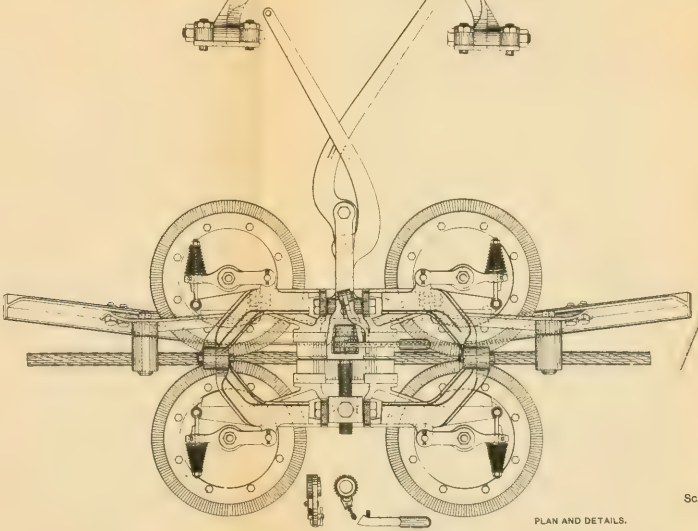
GRIP NOW USED.



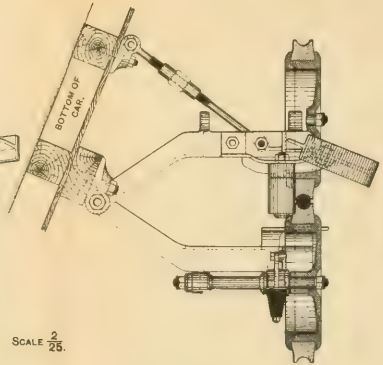
SIDE ELEVATION.



CENTRAL CROSS SECTION.



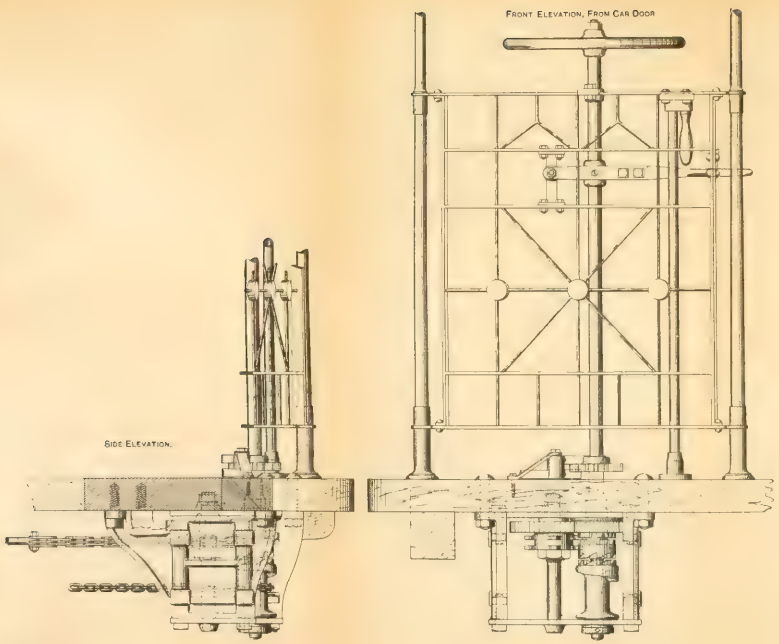
PLAN AND DETAILS.

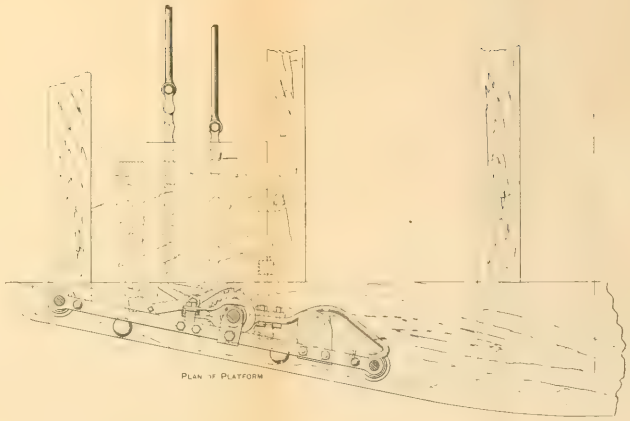



SECTION THROUGH PULLEYS.

SCALE $\frac{2}{25}$.

GEAR FOR OPERATING GRIP AND BRAKES



CAR COUPLER.

PLATE XXIII
TRANS. AM. SOC. CIV. ENG'NS.
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LEVERICH ON BROOKLYN
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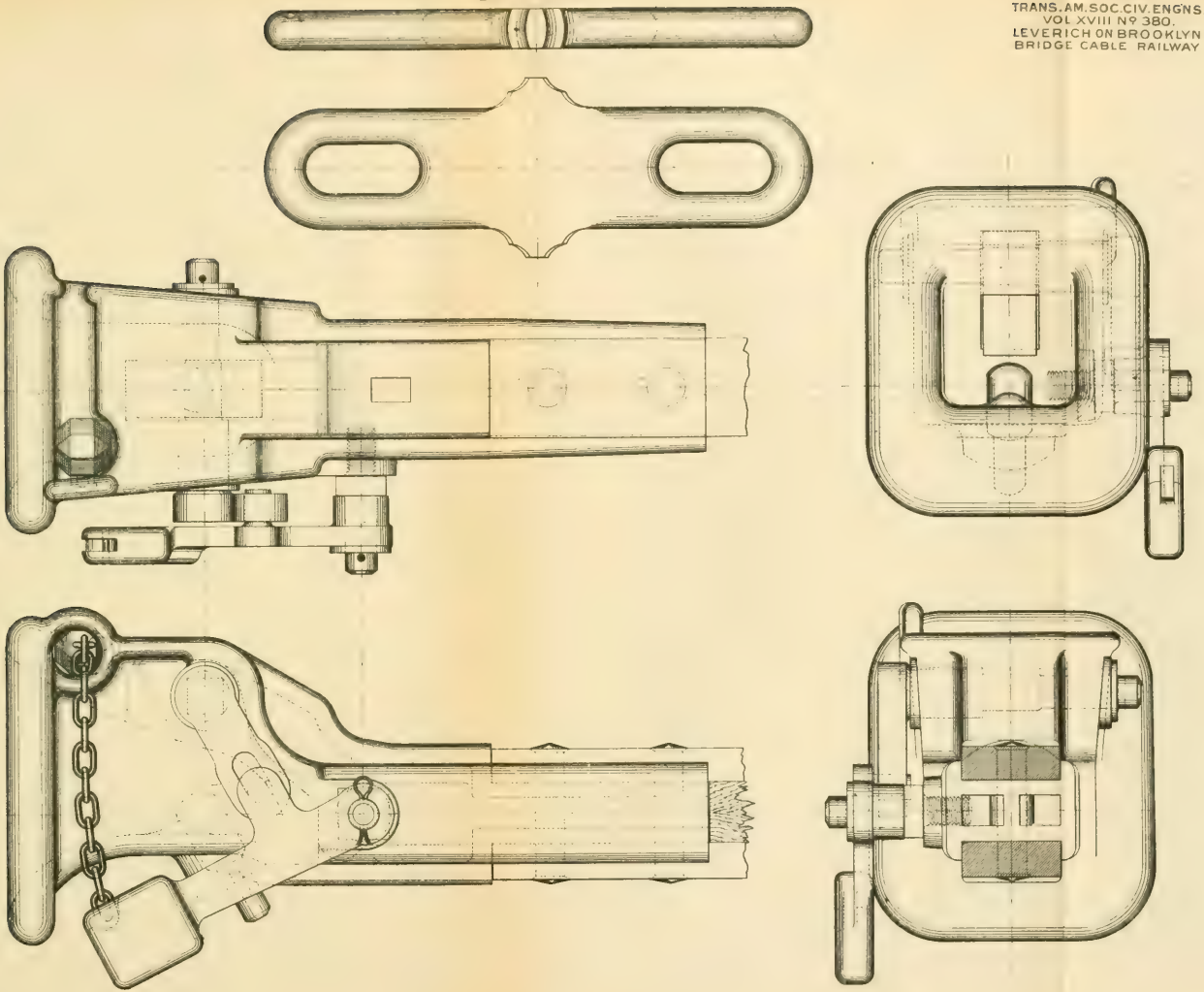
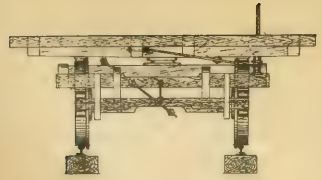
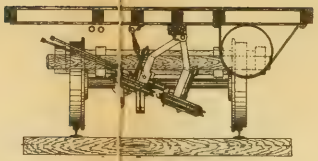


PLATE XXIV
TRANS. AM. SOC. CIV. ENGNS.
VOL XVIII Nº 380.
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

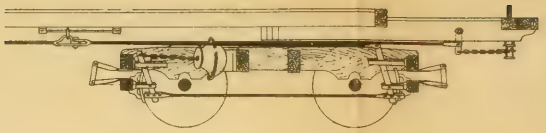
# CAR BOTTOM AND TRUCKS.



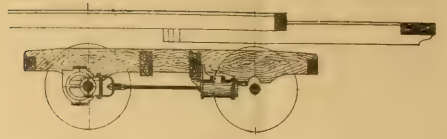
END VIEW SHOWING
BRAKE RODS.



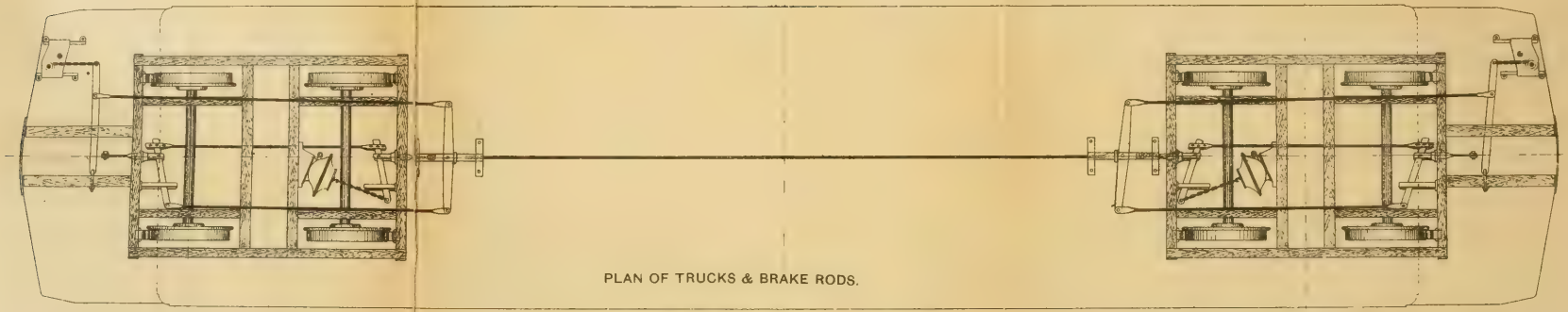
CROSS SECTION SHOWING
GRIP, VACUUM PUMP & RESERVOIR.



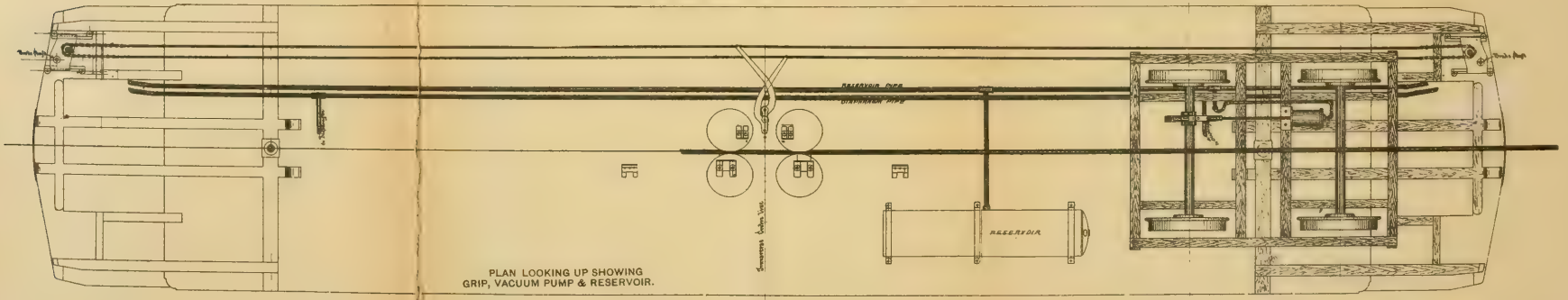
CENTRAL LONGITUDINAL SECTION OF TRUCK, SHOWING
BRAKES, BRAKE LEVERS & DIAPHRAGM.



CENTRAL LONGITUDINAL SECTION OF TRUCK. SHOWING VACUUM PUMP



PLAN OF TRUCKS & BRAKE RODS.




PLAN LOOKING UP SHOWING
GRIP, VACUUM PUMP & RESERVOIR.

PLATE XXV

TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII Nº 380.
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

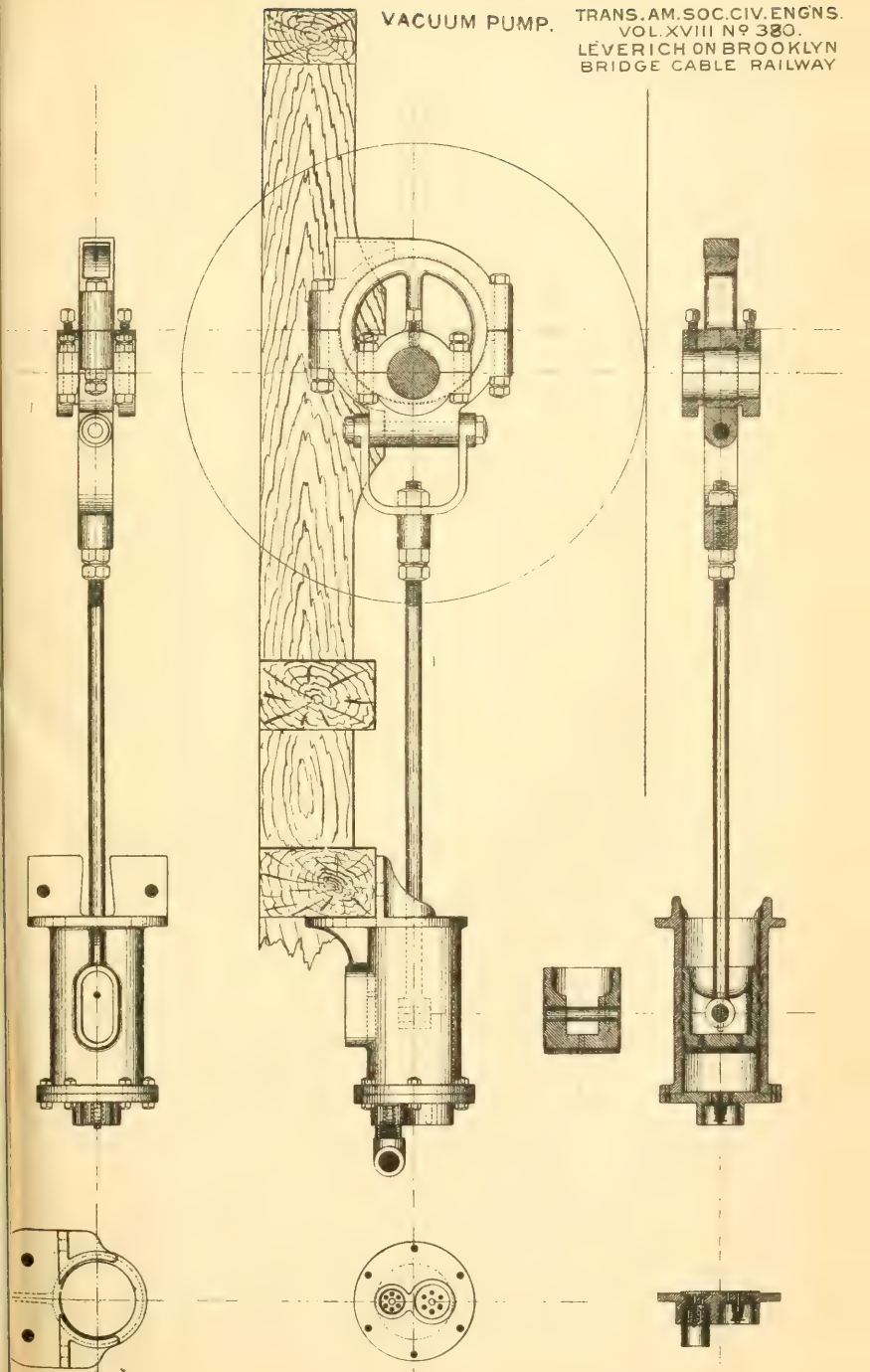
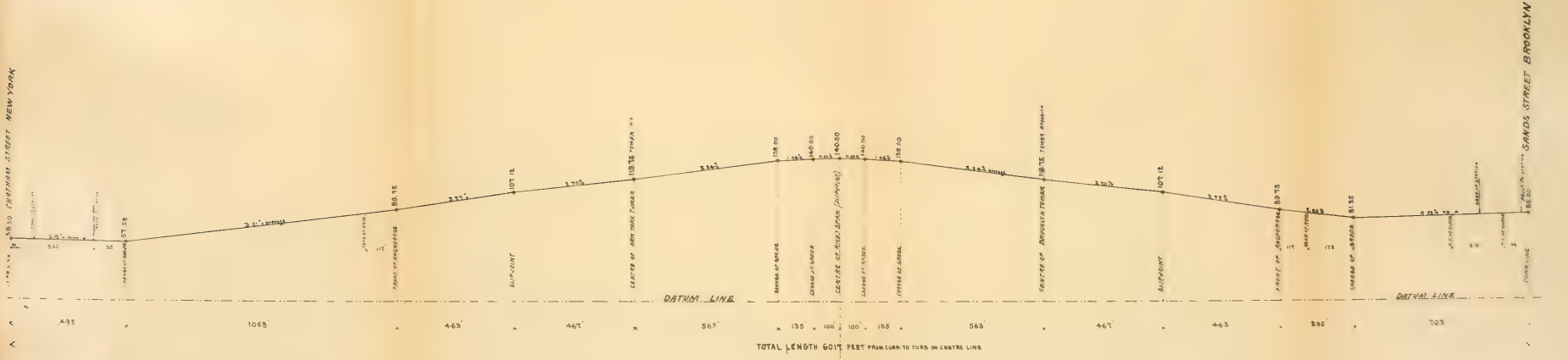
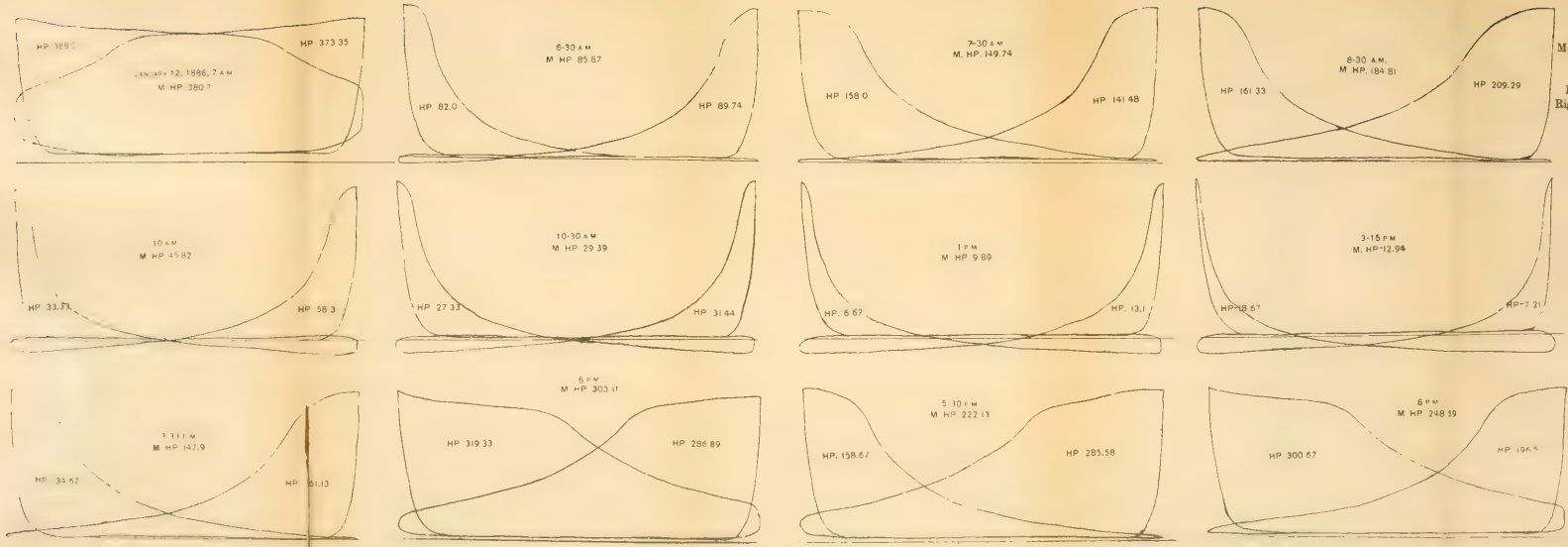


PLATE XXVI
TRANS. AM SOC CIV ENGNS
VOL XVIII No 380
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

# PROFILE OF CABLE RAILWAY.



INDICATOR CARDS FROM WESTERLY ENGINE
ALL TAKEN, EXCEPT AS NOTED, APRIL 26TH 1886




Scale of pressure, 1 40.
Length of diagram 4.4 inches.
Mean speed of engine, 57 revolutions per minute.
Diameter of piston, 26 inches.
Diameter of piston rod, 3½ inches.
Right hand diagram is from crank end of cylinder.

PLATE XVIII.
TRANS. AM. SOC. CIV. ENGNS.
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LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

# DIAGRAM SHOWING INDICATED HORSE POWER OF WESTERLY ENGINE

APRIL 26. 1886.

HORSE POWER

CYLINDER 68" DIA. STROKE 96"
MEAN NUMBER OF REVOLUTIONS PER MIN. WHEN RACING 37 PER MINUTE
MEAN HORSE POWER FOR FULL DAY ..... 96 HORSE 36 H.
FROM 7.30 TO 9.00 A.M. AND 4 TO 5 P.M. 5 HOURS 150.5
AND FOR REMAINDER OF FULL DAY 14½ HOURS 74.4

# DIAGRAM SHOWING POSITION OF TRAINS AND POWER EXPENDED

FROM 4.56 TO 5.45 P. M. NOVEMBER, 1, 1883

Leave Brooklyn

Leave New York

PLATE XXIX
TRANS. AM. SOC. CIV. ENGNS
VOL XVIII Nº 380.
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

CAR 22 with 37 PASS 23.975 lbs

CAR 14 29 PASS 23.500 "

CARS 10+16 " 45 PASS 42.625 "

CARS 11+13 " 51 PASS 40.375 "

CARS 9+21 " 33 PASS 44.000 "

CARS 6+20 " 44 PASS 38.750 "

CARS 4+22 " 43 PASS 42.875 "

CARS 10+16 " 35 PASS 41.375 "

CARS 11+13 " 34 PASS 44.250 "

CARS 9+21 " 30 PASS 40.750 "

CARS 6+20 " 46 PASS 42.500 "

CARS 4+22 " 37 PASS 40.375 "

CARS 10+16 " 42 PASS 42.250 "

CARS 11+13 " 35 PASS 44.375 "

CAR 21 with 50 PASS 26.250 lbs

CAR 22 45 PASS 25.625 "

CAR 14 39 PASS 31.125 "

CARS 10+16 " 111 PASS. 50.875 "

CARS 11+13 " 96 PASS. 49.000 "

CARS 9+21 " 127 PASS 52.375 "

CARS 6+20 " 105 PASS 50.125 "

CARS 4+22 " 113 PASS 51.125 "

CARS 10+16 " 112 PASS 51.000 "

CARS 11+13 " 109 PASS. 54.375 "

CARS 9+21 " 144 PASS. 55.000 "

CARS 6+20 " 145 PASS. 55.125 "

BROOKLYN

NEW YORK

Profile of Bridge

# DIAGRAM SHOWING POSITION OF TRAINS AND POWER EXPENDED

FROM 4.55 TO 5.55 P. M. NOVEMBER, 2, 1883

Leave Brooklyn

Leave New York

PLATE XXX

TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII Nº 380.
LEVERICH ON BROOKLYN
BRIDGE CABLE RAILWAY

CARS 2+21 with 30 PASS 39 500 lbs
CARS 6+13, 37 PASS 41 625 •
CARS 9+20, 31 PASS 40 875 •
CARS 4+16, 33 PASS. 41 000 •
CARS 10+18, 30 PASS 40 750 •
CARS 11+22, 30 PASS 40 750 •
CARS 2+21, 30 PASS 40 750 •
CARS 6+13, 17 PASS 39 125 •
CARS 9+20, 37 PASS 41 625 •
CARS 4+16, 42 PASS 42 250 •
CARS 10+18, 40 PASS 88 250 •
CARS 11+22, 23 PASS. 39 875 •
CARS 6+13 45 PASS 42 625 •
CARS 9+20 20 PASS 39 500 •
CARS 4+16 10 PASS 38 250 •
CARS 2+14 10 PASS 38 250 •
CARS 10+18 5 PASS 37 625 •

CARS 10+18, 52 Pass = 43,500 lbs
CARS 11+22, 89 Pass • 48 125 •
CARS 2+21, 77 Pass. 46 625 •
CARS 6+13, 48 Pass. 43 000 •
CARS 9+20, 67 Pass. 46 375 •
CARS 4+16, 79 Pass. 46 875 •
CARS 10+18, 89 Pass. 48 125 •
CARS 11+22, 76 Pass. 46 500 •
CARS 2+21, 88 Pass. 48 000 •
CARS 6+13 111 Pass. 50 875 •
CARS 9+20, 104 Pass. 50 000 •
CARS 4+16, 87 Pass. 47 875 •
CARS 10+18, 102 Pass. 49 750 •
CARS 11+22, 146 Pass. 55 250 •
CARS 6+13, 181 Pass. 59 625 •
CARS 9+20, 138 Pass. 53 000 lbs

BROOKLYN

NEW YORK

Profile of Bridge

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

381.

(Vol. XVIII.—April, 1888.)

# EXPERIMENTS UPON Z-IRON COLUMNS.

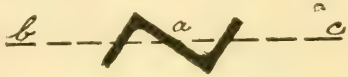
By C. L. STROBEL, M. Am. Soc. C. E.

READ NOVEMBER 16TH, 1887.

About a year ago the writer was called upon to prepare plans and specifications for the superstructure of the new bridge of the Chicago, Milwaukee and St. Paul Railway over the Mississippi River at Kansas City. 1 545 lineal feet of this structure is a double track iron trestle-work of 45 feet average height. It was found that important advantages could be secured for this part of the structure by adopting for the compression members a new form of cross-section consisting of four Z-irons joined by lattice bars in the middle plane, as indicated by sketch.

As Z-irons were not at the time rolled in this country, it was necessary for the mill furnishing this material to prepare rolls specially for the purpose. The Z-shape is obtained by joining two angles as at $a$ in sketch, and the rolling corresponds to the rolling of angle iron, the rolls operating with their axes parallel to the line $b\,c$. It was found that the

rolling of the Z-iron presented no greater difficulty than the rolling of ordinary angle iron.




Notwithstanding the higher price charged, because new rolls had to be prepared to roll the Z-iron, it was furnished by the mill at a much lower rate per pound than channel iron (for which it acted as a substitute) could have been bought for, and a considerable saving in the cost of the structure was thereby effected.

Other advantages of this form of compression member over two channel bars latticed, the usual type, were thought to be the following:

Economy of material in the lattice bars. These are short, and only one set is required, while two must be used in the other form of cross-section.

Economy of manufacture; only two rows of rivets required, whereas four are needed in the other cross-section.

Protected position of lattice bars and consequent freedom from damage during transportation and in handling.

Possibility of effecting better connections with other members in the design of the structure. This feature was considered an important one, as it is held that the efficiency and serviceability of the parts connected are dependent more upon the method and detail of the connection than upon the particular form of cross-section used for the members themselves.

Having adopted the cross-section described for all the columns and struts in the trestlework of the Kansas City Bridge, it was thought advisable to make some experiments to test its efficiency, and prove that the limits to which the members were to be strained in the structure were safe and consistent.

Owing to the large size of the columns in the structure itself, it was not possible to test full-size specimens, therefore smaller columns were used in the experiments, but of the proportions, as near as possible, of those in the structure. The Z-irons in the latter were 3 x 5 x 3 inches in size and $\frac{11}{16}$ inches thick, while in the test columns $2\frac{1}{2}$ x 3 x $2\frac{1}{2}$-inch Z-irons were used-$\frac{5}{16}$-inches thick. Six columns were tested of the lengths 10 feet $11\frac{1}{4}$ inches, 15 feet, and 19 feet $\frac{3}{4}$ inches, two columns for each length. The expense of these tests was borne by the Chicago,

Milwaukee and St. Paul Railway Company. The results proved to be very satisfactory, and the subject was considered of sufficient general importance to be pursued further. It was decided to test nine additional columns of longer lengths, so as to obtain results covering the limits of actual practice. The expense of these tests was jointly borne by the Chicago, Milwaukee and St. Paul Railway Company, and the Keystone Bridge Company. The additional columns tested were 22, 25 and 28 feet long, three columns for each length.

The results of the tests of the entire series of fifteen columns are herewith presented to the Society as a contribution on the subject of the strength of wrought-iron compression members.

The tests were made in the hydraulic testing machine of the Keystone Bridge Company, at their works in Pittsburgh, under the supervision of S. C. Weiskopf, M. Am. Soc. C. E., inspector of shop work, on behalf of the Chicago, Milwaukee and St. Paul Railway Company, for the Kansas City Bridge.

The material was manufactured by Brown, Bonnell & Co., of Youngstown, O. The tests made on specimens cut from the Z-irons are shown in Table No. 3. These tests comprise all that were made on the Z-iron of this size furnished for the Kansas City Bridge. It is difficult to determine the elastic limit accurately on the testing machine used (Riehle's 100,000 pounds machine), and it is probable that the values obtained are too high by several thousand pounds to the square inch in each case.

The first six columns tested were made by M. Lassig, M. Am. Soc. C. E., of Chicago, and the last nine columns by the Keystone Bridge Company, of Pittsburgh.

The columns were placed horizontally in the testing machine, with the lattice bars in a vertical plane, the ends of the columns abutting squarely against the castings of the testing machine without the interposition of shoes. To counteract the tendency of the column to sag from its own weight, an upward pull was caused to be exerted against the middle of the column equal to one-half its own weight.

Plates XXXI and XXXII show the columns tested in detail. Their appearance after the test is plainly shown by the photographs, Plates XXXI, XXXII, XXXIII and XXXIV.

All of the columns failed in the direction in which they were theoretically weakest, and in a uniform manner by deflection.

The results, both in general tabulated form and in detail, will be found appended, Tables Nos. 1 and 2, also a diagram (Plate XXXV), showing the ultimate strengths obtained for all square ended columns tested up to date. This diagram is a reproduction in part of Plate XXXV in Mr. Jos. M. Wilson's paper on "Specifications for Strength of Iron Bridges," Transactions, Vol. XV, p. 366, June, 1886. The tests on octagon columns with diametrical bolts are not included in this diagram because the writer considers this column faulty in design, and it never obtained an extended use and is obsolete now.

It will be seen that the Z-iron columns compare favorably with other columns in ultimate resistance. The values obtained are near approximations to the Watertown results with Phœnix columns, and exceed those heretofore obtained with other types of columns. This favorable showing for the Z-iron columns should probably be attributed to the fact that the material in the outer periphery of the cross-section, on which dependence must be placed to hold the column in line, is not weakened by rivet holes, but is left solid and unbroken, and is, therefore, in the best shape to do its work effectively.

The writer called attention to the small variation in the ultimate strength of columns of the same type for lengths not exceeding 90 radii of gyration (32 diameters), in his discussion of "Experiments upon Phœnix Column" (Transactions, Vol. XI, p. 98, February, 1882). Excluding very short lengths it was found that the ultimate strength up to at least the limit mentioned (90 radii), was practically constant irrespective of the length, though not the same for different types of columns.

The average for Hodgkinson's cylindrical tubes, for lengths ranging from 40 to 90 radii (14 to 32 diameters) was 33 100 pounds per square inch.

The average for the Watertown tests of Phœnix columns for lengths ranging from 40 to 110 radii (14.1 to 39.5 diameters) was 35 800 pounds per square inch.

The average for Mr. Bouscaren's tests of latticed channel columns for lengths ranging from 59 to 90 radii (21 to 32 diameters) was 32 300 pounds per square inch.

The diameters referred to in the above are the diameters of an equivalent cylindrical tube whose area is concentrated in the circumference and whose radius of gyration is the same as that of the section considered.

The present tests on Z-iron columns show no variation in the ultimate strengths for columns 64 radii (23 diameters) and 88 radii (31 diameters) long, the average being 35,650 pounds per square inch.

Tests made by the Keystone Bridge Company for the Baltimore and Ohio Railroad during the construction of the Susquehanna River Bridge, near Port Deposit, on pin bearing steel columns ranging in length from 66 to 98 radii, show a striking uniformity in the ultimate strength.

The only tests which do not seem to conform to the rule mentioned are Mr. Christie's experiments on angles, tees and channels; but these tests are very irregular in their results and seem to defy all law. An explanation for this may, perhaps, be found in the different conditions of end bearing from those which obtain in columns. In the latter the the center of gravity is in the center of the section so that the forces acting at the ends of the column have considerable leverage and are disposed to best advantage to hold the column in line. In solid sections like angles, tees and channels, on which Mr. Christie's experiments were made, not only is the metal grouped nearer to the center of gravity and the end forces therefore act with a smaller leverage, but, owing to the want of symmetry of these sections, there is much less resistance to deflection of the strut in one direction than in another.

Considering all the tests which have been made on hollow columns with square ends, the writer believes that he is justified in assuming that their ultimate strength is constant for lengths up to 90 radii (32 diameters). This assumption is a convenience in the practical work of proportioning the parts of a bridge, because it saves the necessity of calculating the radius of gyration for the chords and end posts, which is a somewhat laborious operation and cannot readily be simplified by means of tables.

In devising a formula which would satisfy the results of the tests on Z-iron columns for lengths beyond 90 radii, the equation of a straight line was found to answer as well as the equation of a curve, while having the advantage of simplicity. The following is the formula selected:

Ultimate strength in pounds per square inch $= 46\,000 - 125\,\frac{l}{r}$ for lengths exceeding 90 radii and 35 000 for lengths equal or less than 90. The diagram, Plate XXXV, gives a graphic representation of the formula, values for which are also contained in the Table No. 1. The deviations from the results of tests are on the safe side.

It has been customary to allow 8 000 pounds per square inch in compression for bridge members of short length, which corresponds to a factor of safety of $\frac{35000}{8000} = 4.35$, when taken with reference to the ultimate strength. Although this factor is slightly less than is customary for tension members (for which the factor is about $\frac{46000}{10000} = 4.6$), it seems ample when the fact is considered that the ratio of elastic limit to allowed strain is the true factor of safety in the ordinary use of a structure, and that this ratio will be greater for compression members than for tension members on the basis of above factor. Indeed, for long compression members which fail by flexure as a whole, the ultimate strength is very little removed from the elastic limit, so that the factor of safety with reference to the elastic limit becomes greater as the length of the member increases, assuming the factor of safety with reference to the ultimate or crippling strength to remain constant. Dividing the constants in the above formula by 4.35, we obtain $10\,600 - 28.5\,\frac{l}{r}$.

For convenience, and as providing additional security for long members, the writer considers it desirable to substitute 30 for 28.5 as the second constant, whence is obtained the following:

Allowed strain in pounds per square inch for square ended Z-iron columns,

$$10\,600 - 30\,\frac{l}{r} \text{ for lengths exceeding 90 radii;}$$

and 8 000 for lengths equal or less than 90 radii.

## TABLE No. 1.

### General Results of Compression Tests of 15 Z-Iron Columns.

Radius of gyration, lattice bars not considered, = 2.05.

Vol. LXVIII, p. 108.

| No. of Statement | No of Column. | Length of Column. | Weight, Pounds. | Sectional Area. Square inches. | Ultimate Strength. Actual. | | Ratio of length to least radius of gyration. | Ult. Str by formula (Rankine Gordon) $\frac{36\,000}{1 \quad \frac{l^2}{36\,000\,r^2}}$ | Ult. Str. by formula $46\,000 - 125\,\frac{l}{r}$ |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | Total Pounds. | Pounds per sq. in. | | | |
| | | Feet. In. | | | | | | | |
| 1 | 3 | 10 $11\frac{1}{4}$ | 421 | 9 435 | 347 100 | 36 800 | 64 | 32 300 | |
| 2 | 4 | " | 441 | 9 984 | 345 800 | 34 600 | " | " | |
| 3 | 2 | 15 0 | 570 | 9 480 | 328 000 | 34 600 | 88 | 29 600 | 35 000 |
| 4 | 5 | " | 560 | 9 280 | 340 000 | 36 600 | " | " | " |
| 5 | 1 | 19 $\frac{3}{4}$ | 699 | 9 241 | 312 000 | 33 800 | 112 | 26 700 | 32 200 |
| 6 | 6 | " | 754 | 10 104 | 340 600 | 33 700 | " | " | " |
| 7 | 7 | 22 0 | 805 | 9 286 | 285 000 | 30 700 | 129 | 24 600 | 29 900 |
| 8 | 8 | " | 805 | 9 286 | 274 300 | 29 500 | " | " | " |
| 9 | 9 | " | 805 | 9 286 | 285 000 | 30 700 | " | " | " |
| 10 | 10 | 25 0 | 900 | 9 156 | 257 400 | 28 100 | 146 | 22 600 | 27 750 |
| 11 | 11 | " | 925 | 9 456 | 265 200 | 28 000 | " | " | " |
| 12 | 12 | " | 930 | 9 516 | 270 400 | 28 400 | " | " | " |
| 13 | 13 | 28 0 | 1 025 | 9 375 | 260 000 | 27 700 | 164 | 20 600 | 25 500 |
| 14 | 14 | " | 1 050 | 9 643 | 270 000 | 28 000 | " | " | " |
| 15 | 15 | " | 1 025 | 9 375 | 258 700 | 27 600 | " | " | " |

## TABLE No. 2.

STATEMENT IN DETAIL OF TESTS.

*Statement No.* 1. *Column No.* 3.

Length of column.....10 feet 11¼ inches.
Sectional area, 9.435 square inches.
Weight.....427 pounds.
Contraction measured in.....9 feet.
Plane of lacing of column placed vertical.

| LOAD. | VERT. DEFLECTION. | | HOR. DEFLECTION. | | CONTRACTION. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 40 000 | .... | .... | .04 | ... | .02 | .... |
| 250 000 | .04 | .... | .10 | .... | .10 | .... |
| 270 000 | .04 | .. | .14 | .02 | .11 | .... |
| 280 000 | .05 | .03 | .15 | .02 | .12 | .... |
| 290 000 | .05 | .03 | .17 | .02 | .12 | .... |
| 300 000 | .10 | .04 | .15 | .07 | .13 | .01 |
| 347 100 | Ultimate | strength. | Failed hor | izontally. | | |

*Statement No.* 2. *Column No.* 4.

Length of column.....10 feet 11¼ inches.
Sectional area, 9.984 square inches.
Weight.....427 pounds.
Contraction measured in.....9 feet.
Plane of lacing of column placed vertical.

| LOAD. | VERT. DEFLECTION. | | HOR. DEFLECTION. | | CONTRACTION. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 40 000 | .... | .... | .... | ... | .... | .... |
| 100 000 | .... | .... | .03 | .... | .04 | .... |
| 180 000 | .03 | .... | .03 | .... | .07 | .... |
| 200 000 | .03 | .... | .05 | .... | .07 | .... |
| 220 000 | .03 | .... | .05 | .... | .09 | .... |
| 240 000 | .03 | .... | .07 | .... | .10 | .... |
| 260 000 | .04 | .... | .10 | .... | .10 | .... |
| 280 000 | .04 | .... | .12 | .... | .12 | .02 |
| 300 000 | .04 | .... | .10 | .03 | .14 | .03 |
| 310 000 | .04 | .... | .10 | .04 | .14 | .03 |
| 320 000 | .04 | .... | .12 | .04 | .14 | .04 |
| 330 000 | .05 | .05 | .12 | .04 | .14 | .04 |
| 340 000 | .15 | .10 | .12 | .07 | .15 | .06 |
| 345 800 | Ultimate | strength. | Failed hor | izontally. | | |

STATEMENT IN DETAIL OF TESTS.

*Statement No. 3. Column No. 2.*

Length of column..... 15 feet.
Sectional area, 9.480 square inches.
Weight..... 565 pounds.
Contraction measured in..... 13 feet.
Plane of lacing of column placed vertical.

| LOAD. | VERT. DEFLECTION. | | HOR. DEFLECTION. | | CONTRACTION. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 40 000 | .06 | .... | .02 | .... | .02 | .... |
| 200 000 | .06 | .... | .12 | .... | .11 | .... |
| 220 000 | .06 | .... | .10 | .... | .12 | .... |
| 240 000 | .06 | .... | .09 | .... | .14 | .... |
| 260 000 | .06 | .... | .12 | .... | .15 | .... |
| 280 000 | .06 | .... | .13 | .02 | .15 | .... |
| 290 000 | .06 | .... | .13 | .03 | .16 | .... |
| 300 000 | .06 | .... | .19 | .04 | .18 | .... |
| 310 000 | .06 | .... | .19 | .07 | .19 | .01 |
| 320 000 | .06 | .... | .28 | .13 | .20 | .04 |
| 328 000 | Ultimate strength. | | Failed horizontally. | | | |

*Statement No. 4. Column No. 5.*

Length of column..... 15 feet.
Sectional area, 9.280 square inches.
Weight..... 565 pounds.
Contraction measured in..... 13 feet.
Plane of lacing of column placed vertical.

| LOAD. | VERT. DEFLECTION. | | HOR. DEFLECTION. | | CONTRACTION. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 40 000 | .12 | .... | .01 | .... | .03 | .... |
| 100 000 | .12 | .... | .01 | .... | .05 | .... |
| 150 000 | .12 | .... | .... | .... | .08 | .... |
| 180 000 | .12 | .... | .03 | .... | .09 | .... |
| 200 000 | .16 | .... | .03 | .... | .10 | .... |
| 220 000 | .17 | .02 | .03 | .... | .12 | .... |
| 240 000 | .17 | .02 | .03 | .... | .14 | .... |
| 260 000 | .22 | .02 | .07 | .... | .15 | .01 |
| 280 000 | .24 | .06 | .07 | .02 | .15 | .02 |
| 290 000 | .26 | .09 | .07 | .04 | .16 | .02 |
| 300 000 | .27 | .11 | .10 | .04 | .17 | .03 |
| 310 000 | .27 | .11 | .11 | .05 | .18 | .04 |
| 320 000 | .27 | .12 | .11 | .09 | .19 | .04 |
| 330 000 | .39 | .17 | .14 | .10 | .19 | .04 |
| 340 000 | Ultimate strength. | | Failed horizontally. | | | |

STATEMENT IN DETAIL OF TESTS.

*Statement No. 5. Column No. 1.*

Length of column..... 19 feet ¾ inches.
Sectional area, 9.241 square inches.
Weight .....729 pounds.
Contraction measured in ..... 17 feet.
Plane of lacing of column placed vertical.

| LOAD. | VERT. DEFLECTION. | | HOR. DEFLECTION. | | CONTRACTION. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 40 000 | .05 | .... | .15 | .... | .... | .... |
| 50 000 | .05 | .... | .15 | .... | .01 | .... |
| 60 000 | .07 | .... | .15 | .... | .02 | .... |
| 70 000 | .07 | .... | .15 | .... | .03 | .... |
| 80 000 | .07 | .... | .15 | .... | .05 | .... |
| 90 000 | .09 | .... | .15 | .... | .05 | .... |
| 100 000 | .09 | .... | .15 | .... | .06 | .... |
| 110 000 | .09 | .... | .15 | .... | .06 | .... |
| 120 000 | .09 | .... | .15 | .... | .07 | .... |
| 130 000 | .09 | .... | .15 | .... | .07 | .... |
| 140 000 | .11 | .... | .15 | .... | .08 | .... |
| 150 000 | .11 | .... | .15 | .... | .09 | .... |
| 160 000 | .11 | .... | .17 | .... | .10 | .... |
| 170 000 | .11 | .... | .17 | .... | .11 | .... |
| 180 000 | .12 | .... | .17 | .... | .12 | .... |
| 190 000 | .14 | .... | .17 | .... | .12 | .... |
| 200 000 | .14 | .... | .17 | .... | .13 | .... |
| 210 000 | .14 | .... | .17 | .... | .13 | .... |
| 220 000 | .14 | .05 | .17 | .... | .14 | .... |
| 230 000 | .17 | .05 | .17 | .... | .15 | .... |
| 240 000 | .17 | .05 | .17 | .... | .16 | .... |
| 250 000 | .18 | .07 | .17 | .... | .17 | .... |
| 260 000 | .20 | .08 | .17 | .03 | .18 | .... |
| 270 000 | .22 | .09 | .14 | .03 | .19 | .... |
| 280 000 | .27 | .09 | .14 | .03 | .20 | .02 |
| 312 000 | Ultimate | strength. | Failed hor | izontally. | | |

STATEMENT IN DETAIL OF TESTS.

*Statement No. 6. Column No. 6.*

Length..... 19 feet $\frac{3}{4}$ inches.
Sectional area, 10.104 square inches.
Weight..... 729 pounds.
Contraction measured in..... 17 feet.
Plane of lacing of column placed vertical.

| Load. | Vert. Deflection. | | Hor. Deflection. | | Contraction. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 80 000 | .08 | .... | .14 | .... | .04 | .... |
| 100 000 | .07 | .... | .14 | .... | .05 | .... |
| 150 000 | .07 | .... | .14 | .... | .08 | .... |
| 180 000 | .08 | .... | .14 | .... | .11 | .... |
| 200 000 | .08 | .... | .14 | .... | .12 | .... |
| 220 000 | .08 | .... | .12 | .... | .14 | .... |
| 240 000 | .10 | .02 | .12 | .02 | .16 | .... |
| 260 000 | .10 | .02 | .12 | .03 | .17 | .... |
| 280 000 | .11 | .04 | .12 | .04 | .19 | .01 |
| 300 000 | .11 | .02 | .08 | .04 | .21 | .02 |
| 310 000 | .12 | .04 | .10 | .05 | .22 | .02 |
| 320 000 | .13 | .04 | .10 | .07 | .23 | .03 |
| 330 000 | .13 | .04 | .10 | .07 | .24 | .03 |
| 340 000 | .11 | .05 | .17 | .15 | .24 | .06 |
| 340 600 | Ultimate strength. | | Failed horizontally. | | | |

STATEMENT IN DETAIL OF TESTS.

*Statement No. 7. Column No. 7.*

Length of column..... 22 feet.
Sectional area, 9.286 square inches.
Weight..... 805 pounds.
Contraction measured in..... 20 feet.
Plane of lacing of column placed vertical.

| Load. | Vert. Deflection. | | Hor. Deflection. | | Contraction. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 100 000 | .07 | .... | .31 | .02 | .07 | .... |
| 150 000 | .08 | .... | .33 | .04 | .12 | .... |
| 170 000 | .08 | .... | .37 | .05 | .15 | .... |
| 190 000 | .08 | .... | .37 | .05 | .16 | .... |
| 200 000 | .08 | .02 | .38 | .07 | .16 | .... |
| 210 000 | .08 | .02 | .38 | .07 | .16 | .... |
| 220 000 | .08 | .03 | .42 | .11 | .19 | .... |
| 230 000 | .08 | .03 | .42 | .11 | .19 | .... |
| 240 000 | .08 | .03 | .43 | .12 | .23 | .... |
| 250 000 | .08 | .03 | .46 | .13 | .23 | .01 |
| 260 000 | .08 | .03 | .49 | .17 | .24 | .01 |
| 270 000 | .08 | .03 | .69 | .31 | .26 | .03 |
| 280 000 | .08 | .03 | 1.04 | .58 | .28 | .05 |
| 285 000 | Ultimate strength. | | Failed horizontally. | | | |

*Statement No. 8. Column No. 8.*

Length of column..... 22 feet.
Sectional area, 9.286 square inches.
Weight..... 805 pounds.
Contraction measured in..... 20 feet.
Plane of lacing of column placed vertical.

| Load. | Vert. Deflection. | | Hor. Deflection. | | Contraction. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 100 000 | .... | .... | .30 | .... | .12 | .... |
| 150 000 | .... | .... | .30 | .... | .12 | .... |
| 170 000 | .... | .... | .35 | .... | .14 | .... |
| 190 000 | .... | .... | .36 | .... | .14 | .... |
| 200 000 | .... | .... | .38 | .... | .17 | .... |
| 210 000 | .... | .... | .38 | .... | .18 | .... |
| 220 000 | .... | .... | .40 | .... | .18 | .... |
| 230 000 | .... | .... | .40 | .04 | .20 | .01 |
| 240 000 | .03 | .... | .46 | .08 | .22 | .01 |
| 250 000 | .04 | .01 | .52 | .11 | .22 | .01 |
| 260 000 | .04 | .02 | .66 | .17 | .23 | .02 |
| 270 000 | .07 | .03 | 1.00 | .48 | .27 | .04 |
| 274 300 | Ultimate strength. | | Failed horizontally. | | | |

STATEMENT IN DETAIL OF TESTS.

*Statement No. 9. Column No. 9.*

Length of column..... 22 feet.
Sectional area, 9.286 square inches.
Weight..... 805 pounds.
Contraction measured in..... 20 feet.
Plane of lacing of column placed vertical.

| Load. | VERT. DEFLECTION. | | HOR. DEFLECTION. | | CONTRACTION. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 100 000 | .08 | .... | .31 | .... | .07 | .... |
| 150 000 | .08 | .... | .31 | .... | .11 | .... |
| 170 000 | .09 | .01 | .33 | .01 | .12 | .... |
| 190 000 | .09 | .01 | .34 | .02 | .14 | .... |
| 200 000 | .09 | .01 | .34 | .02 | .14 | .... |
| 210 000 | .10 | .01 | .35 | .04 | .16 | .... |
| 220 000 | .10 | .01 | .37 | .07 | .17 | .... |
| 230 000 | .10 | .01 | .37 | .06 | .18 | .01 |
| 240 000 | .10 | .01 | .38 | .07 | .18 | .01 |
| 250 000 | .10 | .01 | .40 | .09 | .22 | .02 |
| 260 000 | .10 | .01 | .43 | .12 | .22 | .02 |
| 270 000 | .08 | .01 | .54 | .20 | .25 | .02 |
| 280 000 | .08 | .01 | .77 | .35 | .27 | .04 |
| 285 000 | Ultimate strength. | | Failed horizontally. | | | |

*Statement No. 10. Column No. 10.*

Length of column..... 25 feet.
Sectional area, 9.156 square inches.
Weight..... 900 pounds.
Contraction measured in..... 23 feet.
Plane of lacing of column placed vertical.

| LOAD. | VERT. DEFLECTION. | | HOR. DEFLECTION. | | CONTRACTION. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 100 000 | .04 | .... | .31 | .... | .09 | .... |
| 150 000 | .04 | .02 | .38 | .03 | .16 | .... |
| 170 000 | .04 | .02 | .40 | .04 | .17 | .... |
| 190 000 | .04 | .02 | .43 | .07 | .19 | .... |
| 200 000 | .05 | .03 | .47 | .09 | .20 | .... |
| 210 000 | .05 | .03 | .52 | .10 | .21 | .... |
| 220 000 | .06 | .03 | .58 | .13 | .22 | .... |
| 230 000 | .06 | .03 | .64 | .16 | .24 | .... |
| 240 000 | .07 | .04 | .77 | .22 | .25 | .... |
| 250 000 | .10 | .04 | 1.03 | .35 | .26 | .... |
| 257 400 | Ultimate strength. | | Failed horizontally. | | | |

STATEMENT IN DETAIL OF TESTS.

*Statement No.* 11. *Column No.* 11.

Length of column..... 25 feet.
Sectional area, 9.456 square inches.
Weight..... 925 pounds.
Contraction measured in..... 23 feet.
Plane of lacing of column placed vertical.

| Load. | Vert. Deflection. | | Hor. Deflection. | | Contraction. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 100 000 | .05 | . . . | .08 | .... | .08 | .... |
| 150 000 | .05 | .... | .13 | .... | .13 | .... |
| 170 000 | .05 | .... | .17 | .02 | .17 | . |
| 190 000 | .05 | .... | .22 | .03 | .17 | .... |
| 200 000 | .05 | .... | .26 | .05 | .19 | .... |
| 210 000 | .05 | .... | .28 | .06 | .20 | .01 |
| 220 000 | .05 | .... | .36 | .07 | .22 | .01 |
| 230 000 | .05 | .02 | .41 | .09 | .23 | .02 |
| 240 000 | .02 | .04 | .47 | .12 | .23 | .02 |
| 250 000 | .02 | .04 | .62 | .16 | .25 | .02 |
| 260 000 | .05 | .03 | .98 | .26 | .28 | .02 |
| 265 200 | Ultimate strength. | | Failed horizontally. | | | |

*Statement No* 12. *Column No.* 12.

Length of column..... 25 feet.
Sectional area, 9.516 square inches.
Weight..... 930 pounds.
Contraction measured in..... 23 feet.
Plane of lacing of column placed vertical.

| Load. | Vert. Deflection. | | Hor. Deflection. | | Contraction. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 100 000 | .11 | .... | .26 | .... | .06 | .... |
| 150 000 | .11 | .... | .31 | .02 | .12 | .... |
| 170 000 | .11 | .... | .33 | .03 | .13 | .... |
| 190 000 | .11 | .... | .36 | .03 | .15 | .... |
| 200 000 | .11 | .... | .39 | .04 | .19 | .... |
| 210 000 | .11 | .... | .41 | .05 | .19 | .... |
| 220 000 | .08 | .... | .45 | .06 | .19 | .... |
| 230 000 | .08 | .02 | .48 | .07 | .22 | .... |
| 240 000 | .08 | .02 | .57 | .09 | .24 | .... |
| 250 000 | .08 | .02 | .66 | .14 | .25 | .... |
| 260 000 | .08 | .02 | .84 | .23 | .26 | .... |
| 270 000 | .08 | .02• | 1.30 | .50 | .27 | .02 |
| 270 400 | Ultimate strength. | | Failed horizontally. | | | |

STATEMENT IN DETAIL OF TESTS.

*Statement No.* 13. *Column No.* 13.

Length of column..... 28 feet.
Sectional area, 9.375 square inches.
Weight..... 1 025 pounds.
Contraction measured in..... 26 feet.
Plane of lacing of column placed vertical.

| Load. | Vert. Deflection. | | Hor. Deflection. | | Contraction. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 100 000 | .18 | .... | .18 | .... | .08 | .... |
| 150 000 | .18 | .... | .25 | .... | .16 | .... |
| 170 000 | .18 | .... | .25 | .... | .17 | .... |
| 190 000 | .18 | .01 | .25 | .... | .20 | .01 |
| 200 000 | .18 | .01 | .27 | .... | .22 | .01 |
| 210 000 | .18 | .02 | .32 | .... | .23 | .01 |
| 220 000 | .14 | .02 | .32 | .... | .25 | .01 |
| 230 000 | .13 | .01 | .40 | .04 | .26 | .01 |
| 240 000 | .13 | .... | .50 | .06 | .27 | 02 |
| 250 000 | .11 | .01 | .67 | .12 | .27 | .02 |
| 260 000 | Ultimate strength. | | Failed horizontally. | | | |

*Statement No.* 14. *Column No.* 14.

Length of column..... 28 feet.
Sectional area, 9.643 square inches.
Weight..... 1 050 pounds.
Contraction measured in..... 26 feet.
Plane of lacing of column placed vertical.

| Load. | Vert. Deflection. | | Hor. Deflection. | | Contraction. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 100 000 | .11 | .... | .26 | .... | .12 | .... |
| 150 000 | .11 | .01 | .26 | .... | .16 | .... |
| 170 000 | .13 | .93 | .31 | .02 | .17 | .... |
| 190 000 | .15 | .05 | .33 | .03 | .21 | .... |
| 200 000 | .15 | .05 | .34 | .05 | .23 | .... |
| 210 000 | .16 | .06 | .34 | .05 | .24 | .... |
| 220 000 | .18 | .07 | .36 | .07 | .25 | .... |
| 230 000 | .18 | .07 | .41 | .09 | .25 | .... |
| 240 000 | .21 | .08 | .47 | .11 | .26 | .... |
| 250 000 | .24 | .09 | .55 | .13 | .27 | .01 |
| 260 000 | .25 | .11 | .67 | .17 | .27 | .01 |
| 270 000 | Ultimate strength. | | Failed horizontally. | | | |

STATEMENT IN DETAIL OF TESTS.

*Statement No. 15. Column No. 15.*

Length of column..... 28 feet.
Sectional area, 9.375 square inches.
Weight..... 1 025 pounds.
Contraction measured in..... 26 feet.
Plane of lacing of column placed vertical.

| LOAD. | VERT. DEFLECTION. | | HOR. DEFLECTION. | | CONTRACTION. | |
|---|---|---|---|---|---|---|
| | Temp. | Perm. | Temp. | Perm. | Temp. | Perm. |
| | Inches. | Inches. | Inches. | Inches. | Inches. | Inches. |
| 100 000 | .13 | .... | .10 | .... | .10 | .... |
| 150 000 | .07 | .... | .18 | .... | .14 | .... |
| 170 000 | .10 | .01 | .23 | .01 | .17 | .... |
| 190 000 | .11 | .02 | .28 | .02 | .21 | .... |
| 200 000 | .13 | .02 | .32 | .03 | .23 | .... |
| 210 000 | .13 | .03 | .37 | .04 | .23 | .... |
| 220 000 | .14 | .03 | .41 | .05 | .23 | .... |
| 230 000 | .15 | .03 | .48 | .07 | .24 | .... |
| 240 000 | .18 | .04 | .62 | .07 | .25 | .... |
| 250 000 | .20 | .05 | .80 | .18 | .26 | .... |
| 258 700 | Ultimate strength. | | Failed horizontally. | | | |

## DISCUSSION ON THE STROBEL COLUMN.

By D. J. Whittemore, Past President Am. Soc. C. E.

When I learned that Mr. Strobel would offer a paper for our Transactions on this column, I was exceedingly anxious to secure an advance proof copy of it, as on the result of the tests depended in some considerable measure the safety of an important structure built under my chief direction. On the perusal of that proof I find that Mr. Strobel has fully covered those points to which I wished to call attention, hence I have but little to offer.

When Mr. Strobel first suggested the use of this form of column, I am free to say it did not strike me with favor, but giving it further thought, I concluded to permit its use in the structure under my charge, and it is exceedingly gratifying to me, that the record of tests fully corroborated Mr. Strobel's predictions, given before the tests were made. We must admit, however, that Mr Strobel was not without some authority in making this prediction, as by referring back to his remarks on the tests of the Phœnix columns, published in the Transactions some years ago, we find that he then brought to our attention a form quite similar and the resulting test of it. When we consider that this mass of metal is brought to the requisite form by driving two rows of rivets, its economic cost of manufacture becomes apparent. In this respect it differs and has an advantage over what we designate as the American column, which it resembles to some extent. I wish to acknowledge one fact that operated to govern me somewhat in consenting to the use of the column, and that was that all the parts were outside of the prevailing pool arrangement between makers of channels and beams, for which a higher price must be paid than for angles and other forms. This in our work amounted to several thousand dollars, so we find ourselves many times repaid for whatever was expended for tests.

It strikes me as quite proper that this paper should first appear in our Transactions, since the design of the column is from one of our accomplished members, the consent of its use in an important structure was given by a member; it was manufactured and it was tested by members of our Society. It strikes me that the name given it, "Z-Iron Column," is not a proper one. The forms that go to make this column are now being made of steel, and undoubtedly steel columns will be made of these forms; hence I suggest the propriety of designating this hereafter as the Strobel column, after its designer, and let him to that extent at least have whatever credit shall inure to its design.

## TABLE No. 3.

### Tests of Specimens cut from 3-inch Z-Iron.

(Z irons $2\frac{1}{2} \times 3 \times 2\frac{1}{2} \times \frac{5}{16}$ inches, 8 pounds per foot.)

Iron Manufactured by Brown, Bonnell & Co., Youngstown, Ohio.—Tests made in 100 000 pounds Riehle Machine, at Youngstown, Ohio.

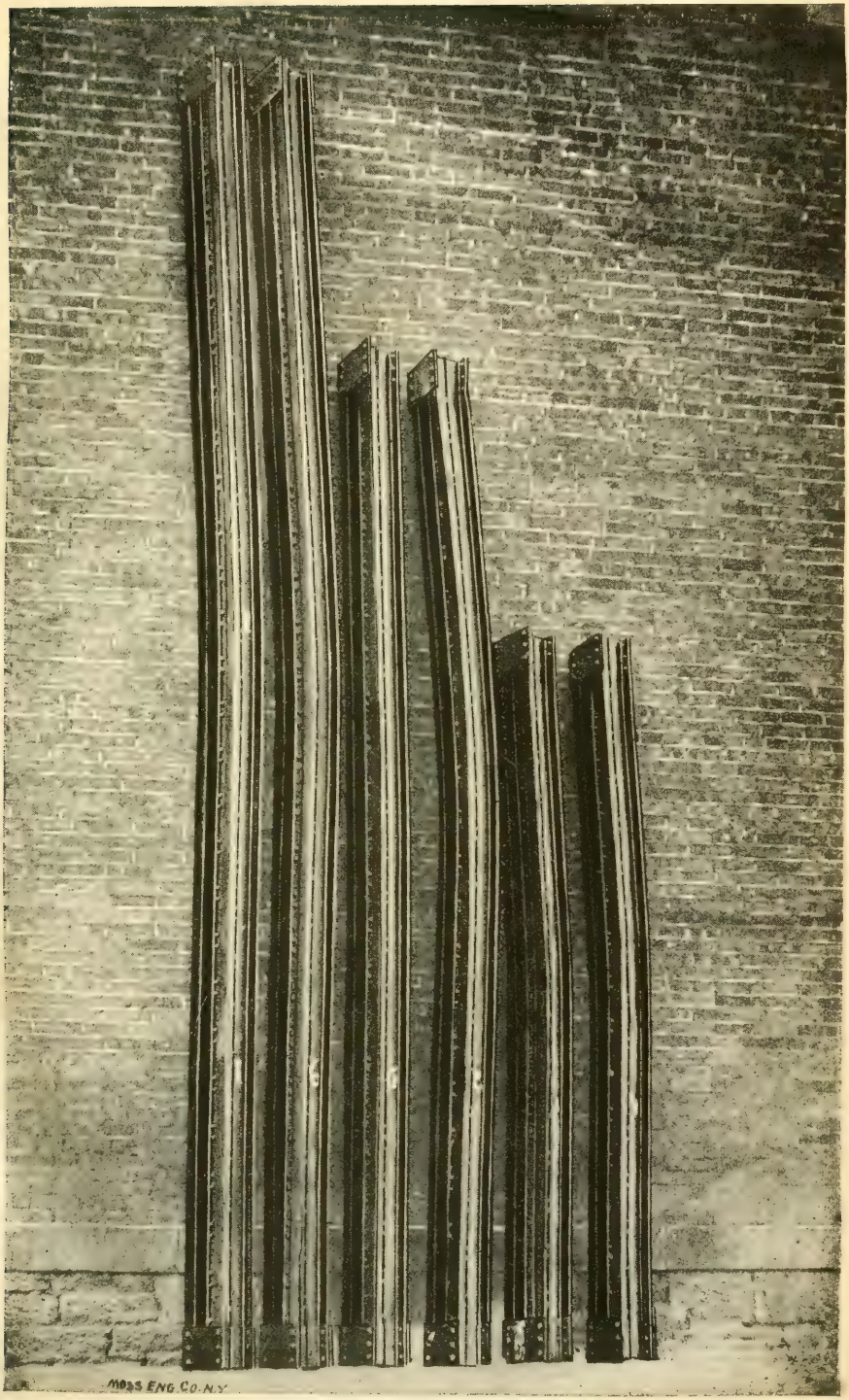
Vol. XVIII, p. 118.

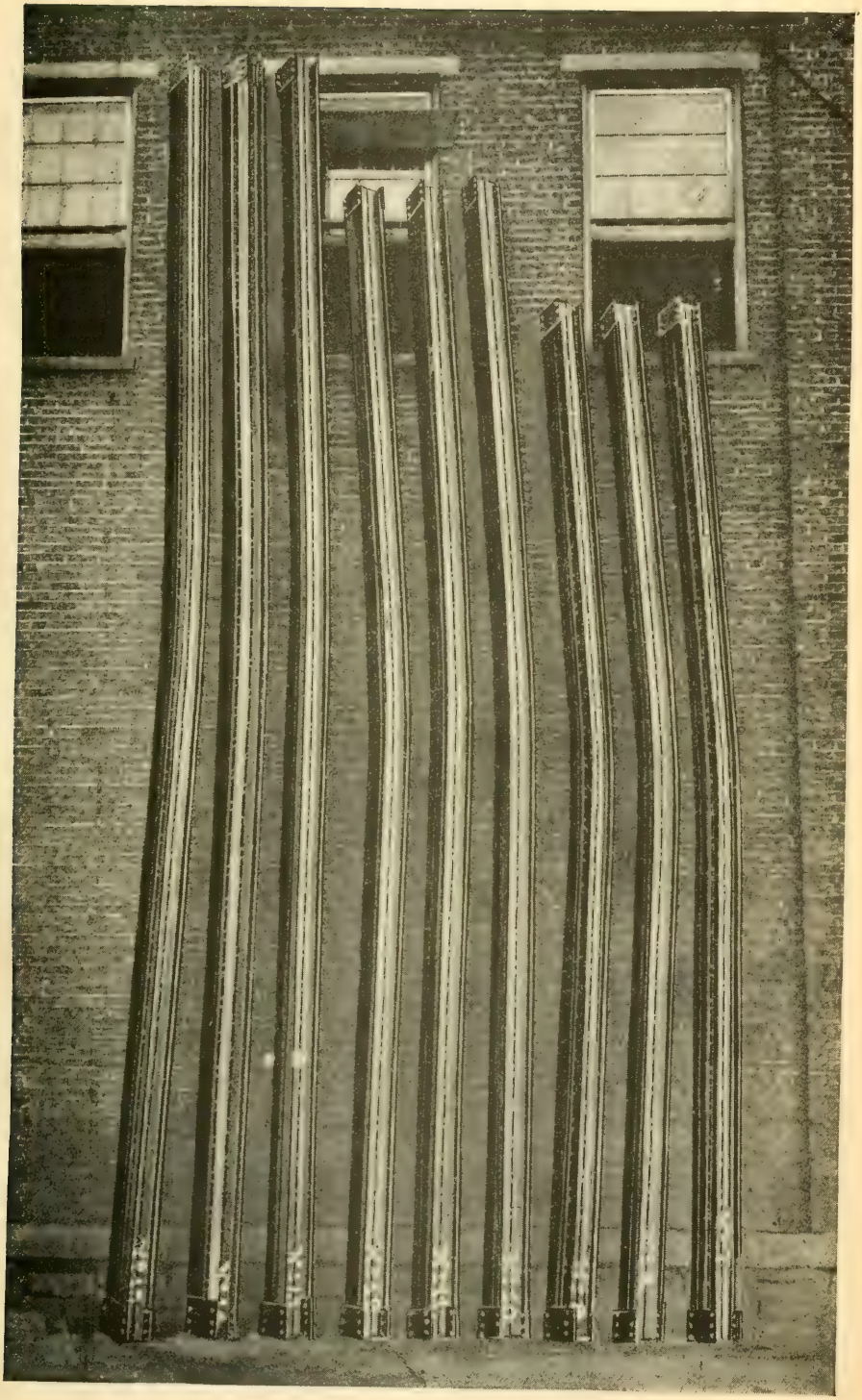
| Date. | Number of Test. | Test Piece Cut From. | Cross Dimensions. Original. | Cross Dimensions. Fractured. | Area. Original. | Area. Fractured. | Area. Per Cent. of Reduction. | Elastic Limit. Actual. | Elastic Limit. Lbs. per Sq. In. | Maximum Load. Actual. | Maximum Load. Lbs. per Sq. In. | Extensions. In 8 Inches. | Extensions. Per Cent. in 8 Inches. | Accepted or Rejected. | Remarks. | Description of Fracture. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1887. | | Inches. | | | | | | | | | | | | | | |
| Feb. 16. | 1 | $2\frac{1}{2} \times 3 \times 2\frac{1}{2}$ Z 8 | 1.433 × .329 | 1.357 × .285 | .4710 | .3920 | 16.70 | 16 130 | 34 200 | 24 100 | 51 160 | 1.20 | 15.00 | Accepted. | Web. | Fracture, fibrous, clean and compact. |
| " | 2 | " | 1.444 × .329 | 1.325 × .285 | .4750 | .3760 | 20.80 | 16 230 | 34 170 | 24 630 | 51 850 | 1.48 | 18.50 | " | Flange. | " " |
| " | 3 | " | 1.449 × .329 | 1.365 × .280 | .4870 | .3820 | 21.60 | 17 280 | 35 480 | 25 080 | 51 500 | 1.04 | 13.00 | " | Web. | " flaw in specimen. |
| " | 4 | " | 1.454 × .333 | 1.350 × .280 | .4840 | .3780 | 21.90 | 16 940 | 35 000 | 25 600 | 52 900 | 1.54 | 19.30 | " | Flange. | " clean and compact. |
| " | 5 | " | 1.481 × .331 | 1.410 × .290 | .4930 | .4090 | 17.10 | 17 280 | 35 000 | 24 440 | 49 570 | 0.96 | 12.00 | " | Web. | " showing crop end. |
| " | 6 | " | 1.498 × .326 | 1.392 × .284 | .4880 | .3950 | 19.00 | 17 260 | 35 300 | 25 200 | 51 700 | 1.32 | 16.50 | " | Flange. | " clean and compact. |
| " | 7 | " | 1.485 × .332 | 1.394 × .290 | .4930 | .4040 | 18.10 | 16 480 | 33 400 | 24 720 | 50 150 | 1.12 | 14.00 | " | Web. | " " |
| " | 8 | " | 1.498 × .326 | 1.345 × .275 | .4880 | .3700 | 24.20 | 16 600 | 34 000 | 25 320 | 51 880 | 1.58 | 19.70 | " | Flange. | " " |
| " 17. | 9 | " | 1.398 × .327 | 1 284 × .267 | .4580 | .3430 | 24.80 | 14 960 | 32 830 | 23 120 | 50 700 | 1.48 | 18.50 | " | " | " " |
| " | 10 | " | 1.404 × .330 | 1 322 × .288 | .4630 | .3800 | 17.50 | 15 180 | 32 760 | 22 700 | 49 070 | 1.13 | 14.00 | " | Web. | " showing crop end. |
| " | 11 | " | 1.399 × .333 | 1.265 × .270 | .4660 | .3520 | 24.40 | 16 430 | 35 360 | 24 530 | 52 650 | 1.81 | 22.70 | " | Flange. | " clean and compact. |
| " | 12 | " | 1.500 × .326 | 1.416 × .276 | .4890 | .3910 | 20.00 | 16 850 | 34 460 | 23 880 | 48 800 | 0.90 | 11.30 | " | Web. | " shows cinder flaw. |
| " | 13 | " | 1.492 × .325 | 1.410 × .280 | .4850 | .3950 | 18.60 | 16 870 | 34 790 | 24 780 | 51 100 | 1.20 | 15.00 | " | Flange. | " clean and compact. |
| " 18. | 14 | " | 1.492 × .330 | 1.407 × .284 | .4920 | .4000 | 18.70 | 16 970 | 34 490 | 24 740 | 50 300 | 1.13 | 14.10 | " | Web. | " broke in grips. |
| " | 15 | " | 1.498 × .335 | 1.370 × .280 | .5020 | .3840 | 23.10 | 17 300 | 34 450 | 25 470 | 50 730 | 1.72 | 21.50 | " | Flange. | " clean and compact. |
| " | 16 | " | 1.502 × .326 | 1 438 × .290 | .4960 | .4170 | 15.00 | 16 870 | 34 400 | 24 950 | 50 900 | 1.12 | 14.00 | " | Web. | " broke in grips. |
| " | 17 | " | 1.497 × .333 | 1.384 × .280 | .4990 | .3870 | 22.50 | 17 140 | 34 100 | 25 140 | 50 400 | 1.30 | 16.50 | " | Flange. | " clean and compact. |
| " | 18 | " | 1.491 × .331 | 1.376 × .275 | .4940 | .3780 | 24.50 | 16 870 | 34 180 | 25 260 | 51 180 | 1.61 | 20.10 | " | " | " " |
| " | 19 | " | 1.455 × .355 | 1.317 × .261 | .4870 | .3440 | 29.50 | 15 210 | 31 230 | 23 900 | 49 060 | 1.54 | 19.25 | " | " | " " |
| " | 20 | " | 1.480 × .337 | 1.380 × .281 | .4990 | .3880 | 22.20 | 15 960 | 32 000 | 24 520 | 49 120 | 1.28 | 16.00 | " | Web. | " " |
| " | 21 | " | 1.370 × .324 | 1.262 × .274 | .4440 | .3560 | 20.00 | 15 340 | 34 300 | 23 680 | 53 300 | 1.40 | 17.50 | " | " | " " |
| " | 22 | " | 1.354 × .330 | 1.245 × .279 | .4470 | .3470 | 22.30 | 14 570 | 32 600 | 23 250 | 52 000 | 1.48 | 18.50 | " | " | " " |
| April 9. | 23 | 3 $2\frac{1}{2} \times \frac{5}{16}$ Z | 1.392 × .330 | 1.293 × .265 | .4594 | .3427 | 25.00 | 15 420 | 33 570 | 21 650 | 47 130 | 0.85 | 11.00 | Rejected. | Flange. | " short and bad. |
| " | 24 | " | 1.383 × .333 | 1.258 × .273 | .4605 | .3434 | 25.00 | 16 750 | 36 380 | 24 380 | 52 940 | 1.66 | 20.75 | Accepted. | " | " clean and compact. |
| " | 25 | " | 1.370 × .334 | 1.244 × .277 | .4576 | .3446 | 25.00 | 14 970 | 32 720 | 23 240 | 50 790 | 1.66 | 20.75 | " | " | " " |
| " | 26 | " | 1.456 × .321 | 1.353 × .263 | .4674 | .3558 | 24.00 | 16 780 | 35 900 | 25 630 | 54 820 | 1.52 | 19.00 | " | Web. | " " |
| " | 27 | " | 1.460 × .322 | 1.361 × .263 | .4701 | .3580 | 24.00 | 16 400 | 34 890 | 24 770 | 52 700 | 1.26 | 16.00 | " | " | " " |
| " 13. | 28 | " | 1.493 × .320 | 1.367 × .266 | .4746 | .3636 | 23.00 | 15 800 | 33 290 | 24 240 | 48 970 | 0.89 | 11.00 | Rejected. | " | Fracture, unwelded, dirty. |
| " | 29 | " | 1.490 × .340 | 1.340 × .280 | .5066 | .3752 | 26.00 | 18 240 | 36 010 | 26 250 | 51 820 | 1.59 | 20.00 | Accepted. | Flange. | Fracture, fibrous, clean and compact. |
| " | 30 | " | 1.430 × .337 | 1.332 × .280 | .4819 | .3729 | 23.00 | 16 340 | 33 910 | 23 920 | 49 640 | 0.96 | 12.00 | " | " | " " |
| " | 31 | " | 1.421 × .322 | 1.335 × .275 | .4576 | .3671 | 20.00 | 15 450 | 33 770 | 22 440 | 49 040 | 0.89 | 12.00 | " | Web. | " " |
| May 11. | 32 | " | 1.373 × .349 | 1.251 × .296 | .4792 | .3703 | 23.00 | 16 700 | 34 850 | 24 720 | 51 920 | 1.44 | 18.00 | " | Flange. | " " |
| " | 33 | " | 1.400 × .334 | 1.237 × .275 | .4676 | .3402 | 27.00 | 15 750 | 33 680 | 23 730 | 50 730 | 1.61 | 20.00 | " | " | " " |
| " | 34 | " | 1.369 × .329 | 1.238 × .265 | .4504 | .3281 | 27.00 | 15 930 | 35 370 | 23 220 | 51 550 | 1.56 | 20.00 | " | " | " " |
| " | 35 | " | 1.376 × .315 | 1.275 × .262 | .4334 | .3341 | 23.00 | 14 160 | 32 670 | 20 040 | 46 240 | 0.91 | 11.00 | Rejected. | Web. | " short, bad flaw. |
| " | 36 | " | 1.375 × .324 | 1.297 × .283 | .4455 | .3670 | 18.00 | 15 260 | 34 250 | 21 620 | 49 000 | 1.00 | 12.50 | Accepted. | " | " clean and compact. |
| " | 37 | " | 1.346 × .319 | 1.262 × .272 | .4294 | .3433 | 20.00 | 14 680 | 34 190 | 20 919 | 49 000 | 1.04 | 13.00 | " | " | " " |
| " | 38 | " | 1.458 × .315 | 1.359 × .264 | .4593 | .3588 | 23.00 | 15 070 | 32 810 | 22 720 | 49 470 | 1.25 | 16.00 | " | " | " " |

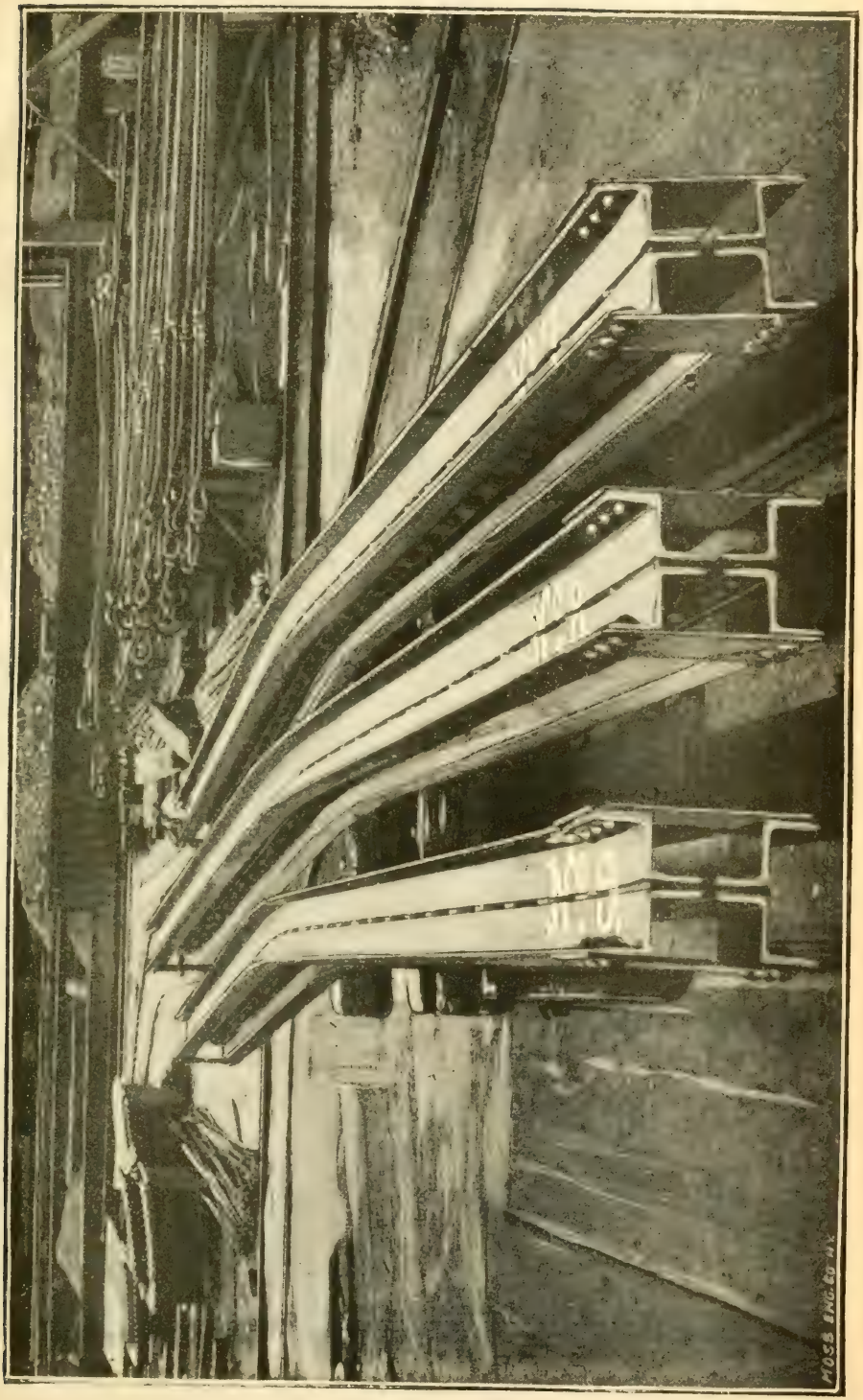
Note.—Bending tests and nicking tests made, one each for every tension test, and they were found very satisfactory.

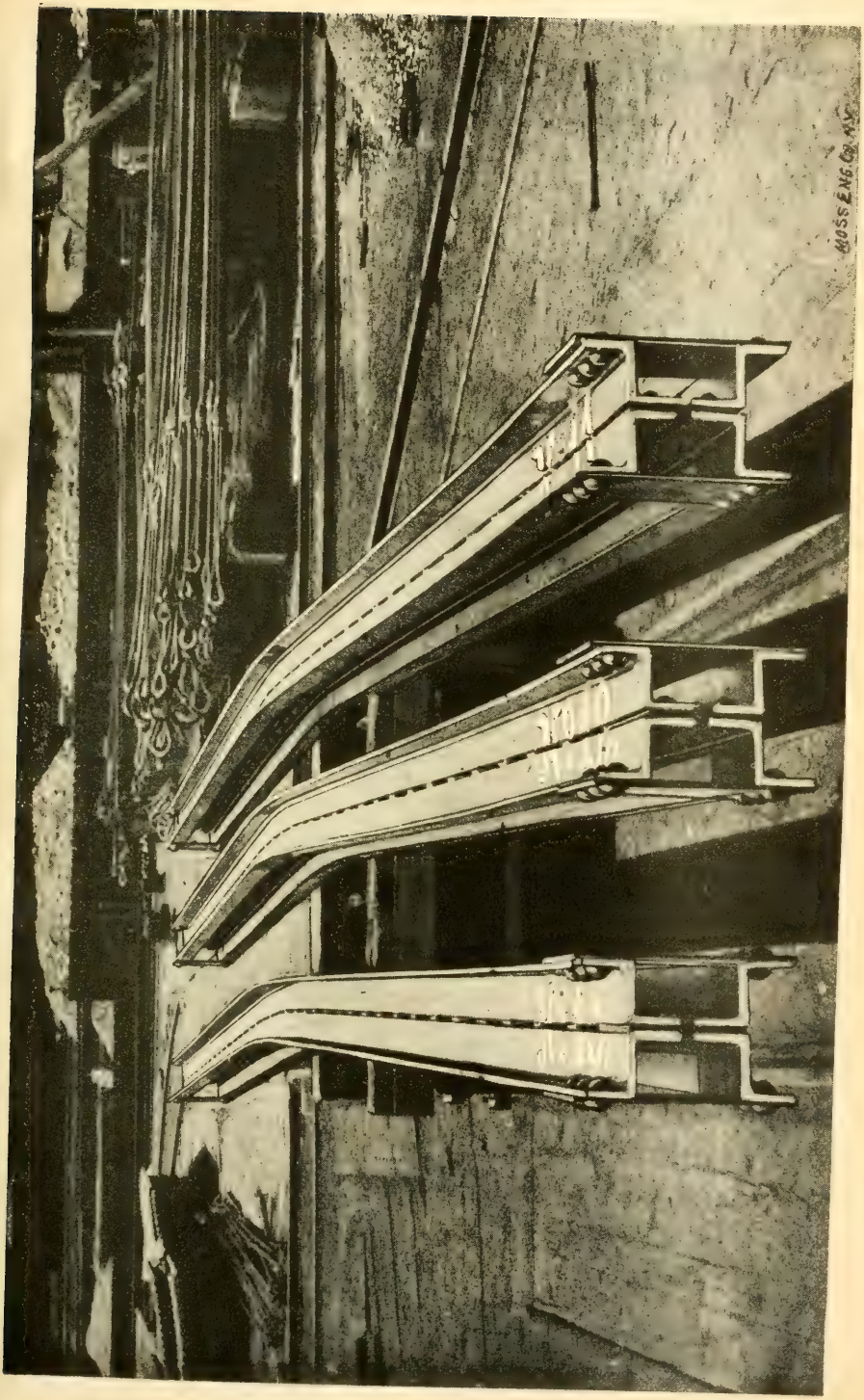
Brackets to right of sheet connecting any two tests, as for instance tests Nos. 19 and 20, indicate that these specimens were cut from same piece of Z, one from the flange and one from the stem or web.

PLATE XXXI.
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XVIII. NO. 381.
STROBEL ON
Z-IRON COLUMNS.






MOSS ENG.CO. N.Y.


MOSS ENG. CO. N.Y.

Values of length divided by least radius of gyration

PLATE XXXV
TRANS. AM. SOC. CIV. ENGRS
VOL. XVIII N° 381
STROBEL ON
Z IRON COLUMNS

Breaking loads in the per-square inch.

Breaking loads in pounds per square inch.

formula 56100 − 125 l/r

Notation

P Phoenix Iron Co columns Phoenixville U.S. tested at Watertown U.S. Trans. Am. Soc. Civ. Engrs Feb. 1882.
W Experiments Watertown Arsenal U.S. Report of 1881
C Experiments Cincinnati Southern Railway made in Chicago and Pittsburgh U.S. G. Bouscaren C.E. Trans. Am. Soc. C.E. Dec. 1880
□ Box Channel columns
× Lattice Channel columns
⊙ Phoenix Iron Co columns
I American Bridge Co columns

Experiments by Mr. James Christie C.E. Pencyd Iron Works Pennsylvania U.S. Trans. Am. Soc. C.E. Apr. 1884

△ Flat Ends
⊕ Fixed Ends
L = Angles
T = Tees
[ = Channels
I = Beams
WL = Watertown Channels
○ = Welded tubes

Two plates at ends

lattice

Phoenix Bridge Co | Keystone Bridge Co | Z Post | American Br. Co. | Channels with plates / Channels with lattice, sides same here

Values of length divided by least radius of gyration.

PLATE XXXVI
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XVIII Nº 382.
BOLLER ON TEST OF
WROUGHT IRON FLOOR BEAM.


SIDE ELEVATION
of
HALF OF FLOOR BEAM
Flange angles 6" x 6" x ½"
40 Spaces @ 3" each.
Web plate 41¾" x ⅜" x 25' 5½"
Extra cover plate 14" x ½" x 14'6"
Cover plate 14" x ½" x 25' 5½"
All rivets ⅞" diam.
Cover plate 14" x ½" x 26' 1"
Gusset plate for lateral braces
Riveted to posts of truss
d = 21"
d = 23¾"
3'6" back to back of angles
5' 0"
4' 7¼"
3' 1½"

PLATE XXXVII
TRANS. AM. SOC. CIV. ENG'RS.
VOL. XVIII Nº 382.
BOLLER ON TEST OF
WROUGHT IRON FLOOR BEAM.

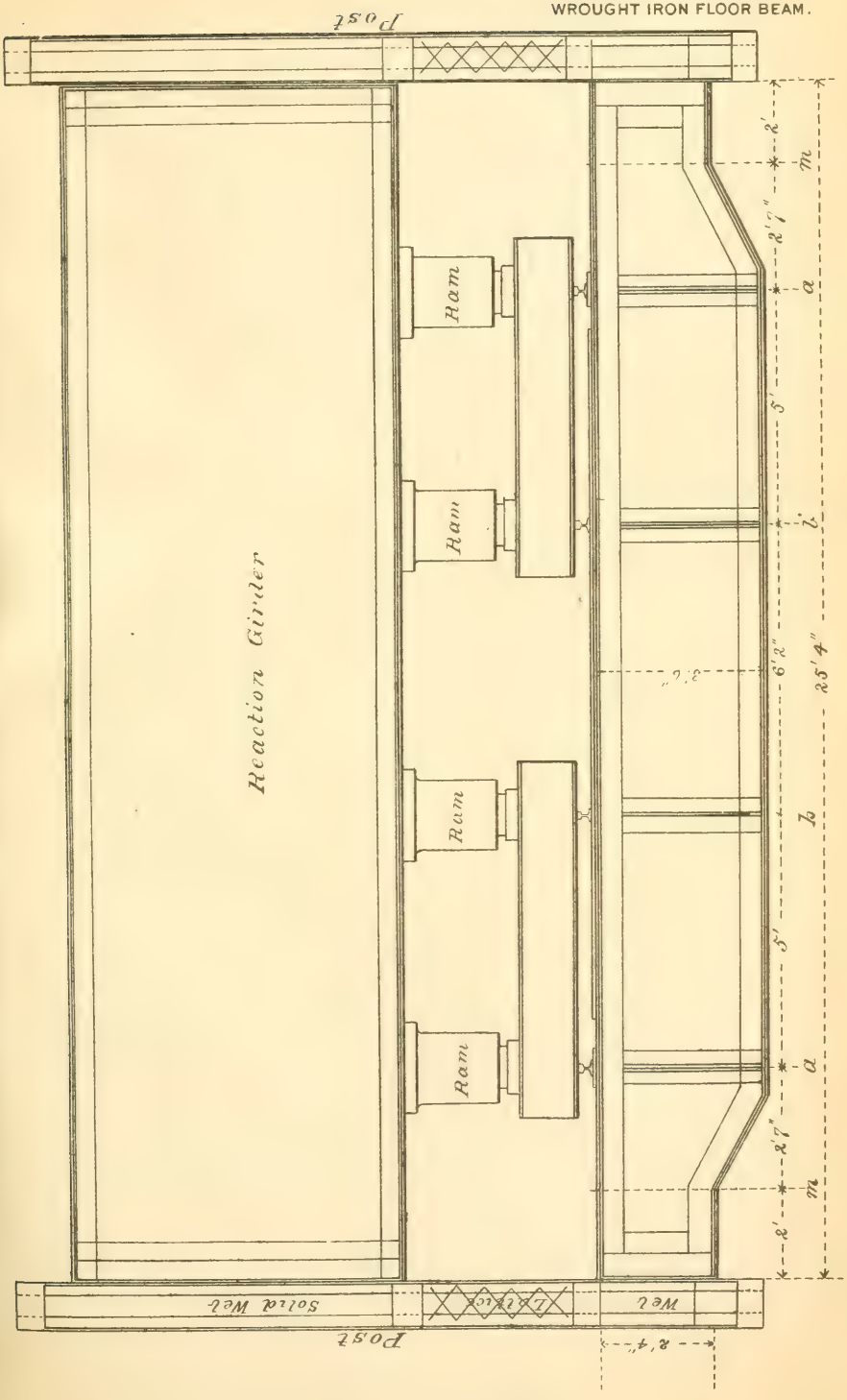
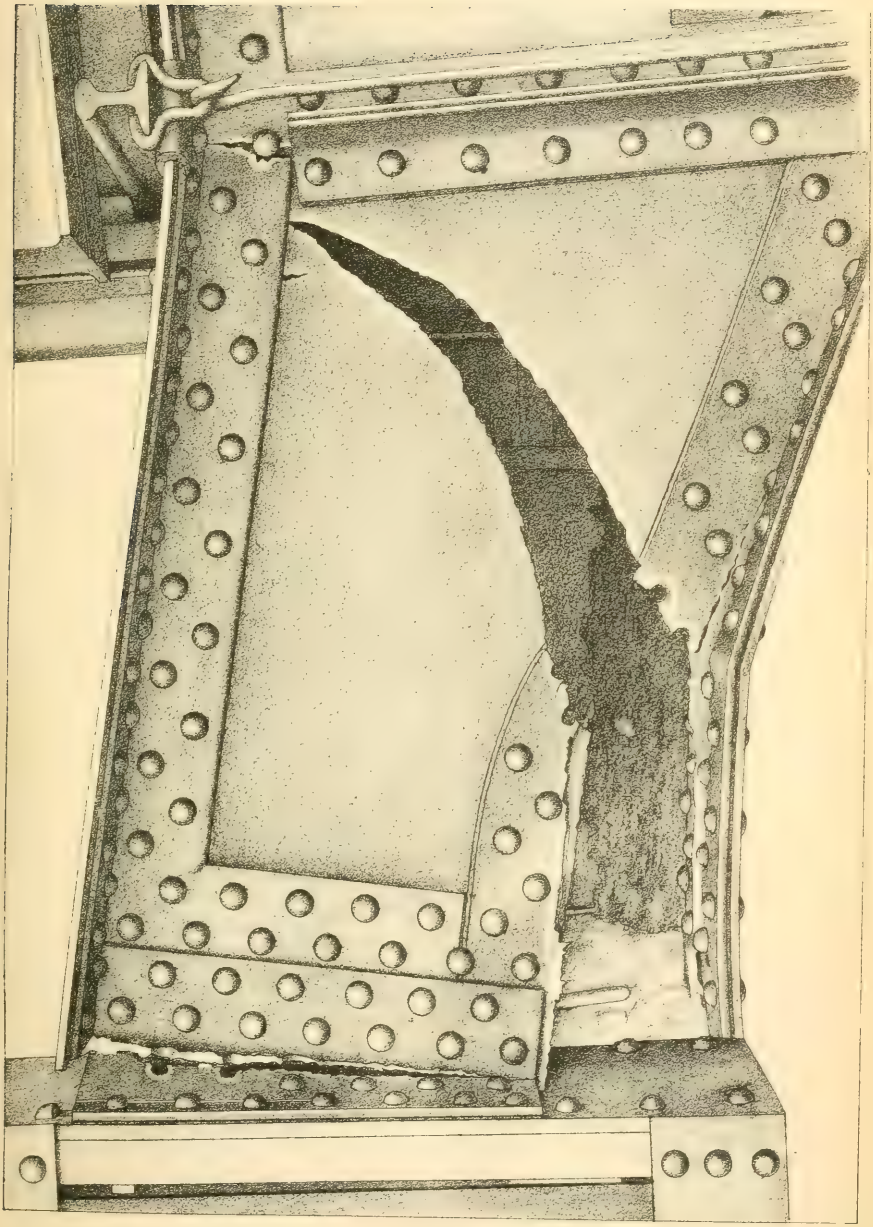


PLATE XXXVIII
TRANS. AM. SOC. CIV. ENGRS.
VOL. XVIII Nº 382.
BOLLER ON TEST OF
WROUGHT IRON FLOOR BEAM



AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

382.

(Vol. XVIII.—May, 1888.)

# TEST OF A WROUGHT IRON DOUBLE TRACK FLOOR BEAM.

By ALFRED P. BOLLER, M. Am. Soc. C. E.

READ NOVEMBER 16TH, 1887.

## WITH DISCUSSION.

Testing to rupture actual bridge members is always a matter of great scientific interest, and while the record is quite extensive in eye-bars, posts, or small parts, the great cost, time and inconvenience of handling heavy girders, has prevented experiment in that direction. In fact, the writer is unaware of any experiment upon compound riveted beams, on a large scale, as actually used, until the experiment recorded below was made, under his supervision.

The beam was an exact duplicate of those in use on a bridge, about which more or less controversy had arisen, and to settle the different views of "experts" as to their practical safety, the company ordered a test made under, as near as possible, actual conditions of attachment and loading. Plates XXXVI and XXXVII show the form and proportion of the beam, and connection with the posts, together with the position of the track stringers. The actual static loads to which the beam could be subjected by the heaviest engines in use on the road, with weight of

floor is 40 000 pounds at each stringer bearing. The strains computed therefrom being as follows:

Flange strains at $m$ 3 800 pounds per square inch.
" " $a$ 5 700 " "
" " $b$ 6 400 " "
Shear strains in web between $a$ and $b$, 2 600 pounds per square inch.
" " between $a$ and end.
8 000 pounds per square inch, at least section, or where web is 2 feet four inches deep, or 42 diameters between angle-iron.

Rivets.—All rivets $\frac{7}{8}$ inches diameter or $\frac{1}{16}$ when driven to fill holes—area of section 0.6 square inches, bearing area diameter x $\frac{3}{8}$ plate=0.35 square inches, and for $\frac{1}{2}$-inch plate 0.47 square inches.

Post attachment considering all the 26 rivets doing duty, yields rivet strain as follows, in shear (single)..... 5 000 pounds per square inch.
and bearing area ($\frac{1}{2}$-inch plate,) 6 600 " "

CONNECTION OF $\frac{3}{8}$ WEB TO FLANGE ANGLES:

Taking the 40 rivets between ends of girder and second stringer, the horizontal strain difference is 162 000 pounds. the rivets being strained 3 400 pounds per square inch double shear, and 11 600 pounds per square inch bearing area.

Taking distance from ends to first stringer, the horizontal strain difference is 105 000 pounds yielding on 20 rivets. 4 200 pounds per square inch double shear, and 15 000 pounds per square inch bearing area.

Taking a short distance of two feet from ends, the horizontal strain is 70 000 pounds on 10 rivets, giving 5 800 pounds per square inch double shear, and 20 000 pounds per square inch bearing area.

In these girders, the weakness feared was in the end flange riveting and shear in end web, and caused the test recorded below.

The test was recently made at the works of the Keystone Bridge Company, by means of hydraulic power applied at stringer points; convenience made it necessary to make the test with the beam blocked up horizontally on the ground, so that the weight of the beam is necessarily neglected. The beam was connected with a pair of posts, precisely as in the actual structure, between which an additional girder was framed as a reaction base for the rams. Plate XXXVII shows the general arrangements. The hydraulic power was derived from the testing machine plant of the Keystone establishment, and the deflections measured from a fine wire parallel to lower flange, and about 3 inches

therefrom. The diameter of the rams was 10 inches. (Area 78.54 inches.) The record was as follows:

| Gauge Reading. | Load on each Ram. | Deflections. $b$. | Deflections. $b'$. | Total Load. |
|---|---|---|---|---|
| 565 | 44 375 pounds. | $\frac{1}{8}$ inch. | $\frac{1}{8}$ inch. | 177 500 pounds. |
| 1 130 | 88 750 " | $\frac{5}{16}$ " | $\frac{5}{16}$ " | 355 000 " |
| 1 412 | 110 900 " | $\frac{3}{8}$ " | $\frac{3}{8}$ " | 443 600 " |
| | No permanent set in above. | | | |
| 1 695 | 133 125 pounds. | Uncertain. | | 532 500 " |
| | Permanent set scant $\frac{1}{32}$ of an inch. | | | |
| 1 980 | 155 500 | Not recorded. | | 622 000 " |
| | Permanent set $\frac{5}{32}$ of an inch. | | | |
| 2 080—Failure commenced through giving way of angle-irons beginning in a fine seam..... | | | | 653 500 " |

—at first bend in lower flange, from end support, the seam being along the root of the angle, which continual pressure tore apart across the angle as shown, when the web commenced to tear like a sheet of paper, in direction and manner as exhibited on Plate XXXVIII herewith (from photograph). From some cause, not apparent, the deflections were not similar at the symmetrical end rams ($a$), the point where the web failed (left side) being sharply deflected. While the angles showed root fracture at the opposite point, the web did not fail or show indications of so doing, the deflection being on an easy curve. With the extreme yielding of the lower flange angles, the angle brackets connecting girder with posts, commenced to go, tearing likewise along the root, and stripping the heads from the extreme upper rivets as shown. The internal diaphragm connecting the channel sides of the posts, was unaffected.

The rivets connecting the ruptured flange with web appeared as perfect as when driven, and no indication was disclosed, as far as it was possible to tell, of the holes in the web elongating, or any upsetting of bearing surface. There is no telling what the web and rivets would have borne, had not the solid angle-irons given way, at the first bend.

It is to be noted that flange plate, with leg of angle attached thereto, was intact, showing no indication of rupture.

*Discussion.*—Taking that stage of the experiment when a permanent set was first noted, viz.: $\frac{1}{32}$ of an inch, the recorded load was 532 500 pounds, or as near as may be $3\frac{1}{3}$ times the basis on which the calculations in the first part of this paper were made (40 000 pounds on each stringer or 160 000 pounds total). Applying this ratio to the preceding computations, the iron would be apparently strained as follows:

| | | | | | |
|---|---|---|---|---|---|
| Flanges | at $m$ | 3 800 × $3\frac{1}{3}$ | = 12 600 | pounds per | square inch. |
| | $a$ | 5 700 × " | = 19 000 | " | " |
| | $b$ | 6 400 × " | = 21 200 | " | " |
| Web | between $a$ and $b$ | 2 600 × " | = 8 700 | " | " |
| | least section | 8 000 × " | = 26 600 | " | " |
| Rivets | Post attachment, bearing area | 6 600 × " | = 22 000 | " | " |
| | Post attachment, double shear | 5 000 × " | = 16 600 | " | " |
| | Web and flange connections end rivets, bearing area | 20 000 × " | = 66 600 | " | " |
| | Web and flange connections end rivets, double shear | 5 800 × " | = 19 300 | " | " |

When failure in angles was first noted, the recorded load was 653 500 pounds, or slightly more than four times the computed basis of load, which would increase the above strains about one-fifth, giving a calculated flange strain when angle failed of some 15 000 pounds per square inch—and bearing area strain on end flange and web rivets about 80 000 pounds per square inch—neither of which could possibly be true, or the web would have torn out from the rivets, and the flanges be perfectly sound, well within elastic limits, although in the last case it is to be noted that the horizontal table of the flange was perfectly sound, the flange failure commencing primarily with a long split along the weld of the angle-iron root, throwing the whole flange duty upon the vertical legs of the angle-irons when a rupture strain was quickly reached. Had the angles been rolled from a solid ingot, or on the German method of developing from a flat, instead of from the ordinary welded pile, the strength of this beam would have been largely increased. The prime weakness in the beam was due therefore to the mode of manufacturing the angle-irons, which were weak along the weld at the root. This was also shown in the end bracket angles uniting the beam to the posts.

The experiment further shows that a plate web is an exceedingly stiff member, much stiffer than is commonly supposed, all formula for proportioning the same being utterly in the fog, the dicta of one expert being about as good as that of another. It demonstrates that the customary method of proportioning rivets, viz., the horizontal component between any two given points, divided by allowable bearing pressure per square inch equals number of rivets required, is not true, and that the friction due to power riveting has enormous value.

This beam was reported to the company interested as practicably safe by the writer, on general considerations, before the experiment was made, and the opinion reaffirmed after the experiment.

# DISCUSSION.

GEORGE DEVIN, M. Am. Soc. C. E.—Reviewing the subject discussed in the interesting paper so kindly submitted to the Society by Mr. Boller, I find that the results are entirely in harmony with well understood and accepted principles in mechanics and that the strength of materials developed in the test coincides with the results prescribed in our every-day engineering practice.

I would quote the usual specification for the strength of material under the various conditions here brought into play:

| | Pounds per Square Inch. |
|---|---|
| Ultimate strength in the direction of the grain of plate and angle | 45 000 to 48 000 |
| Strength across the grain | 32 000 to 40 000 |
| The crushing strength of wrought-iron in short lengths or in partly confined sections applicable to rivet bearings | 60 000 to 70 000 |
| Shearing strength of plate iron | 40 000 |
| Shearing strength of iron rivets | 40 000 to 42 000 |

Where diagram and original data is called for in this article, reference is made to the original drawing (Plates XXXVI and XXXVII) and the data given in Mr. Boller's paper.

It is the usual practice in proportioning plate girders to assume that the bending or chord stresses are resisted entirely by the flanges and the shearing or web stresses as resisted entirely by the web. Strictly speaking, this assumption is not true. The result of our proportions as usually made being a slight surplus in the material available for flange duty. Accurately considered, one-sixth of the web is available for and does flange duty. Wishing to examine as accurately as possible the conditions of stress in the girder under consideration, we will take into account the resistance to bending available in the web.

Since in built girders formed of plates and angles, as in this case, the only stress on the flange comes through the connection of the web to the flange, we may properly take the efficiency of the connection as the available flange section (assuming that the flange is equal to or in excess of the connection).

Referring to the data given in the experiment, we have as the end reaction at the instant of failure, 326 000 pounds, and the resulting horizontal or chord stress at the point $m = 284\,000$ pounds to be resisted by the rivet connection plus so much of the web as is available for flange duty. That is, the bearing section of ten $\frac{1}{16}$-inch rivets on $\frac{3}{8}$-inch plate $= 3.5$ square inch plus one-sixth of the web plate whose net section is 26 inches $\times \frac{3}{8}$-inch $= 1.6$ square inches, giving us a total section of a little more than 5 square inches. Then we have as the stress imposed per unit on the available section $\frac{284\,000}{5}$ pounds $= 56\,800$ per square inch.

Under the foregoing assumption, this then is the stress imposed alike on the rivet-bearing and on the web section available for flange duty. This is true for the compression flange when the bearing capacity of the rivet and the web plate is the same.

Considering now the tension flange or the lower chord at the point $m$, we have from our previous deduction the section of the flange material proper made available for duty by means of the strength of the rivet connection, $3\frac{1}{2}$ square inches out of a total section at that point of $18\frac{1}{2}$ square inches.

Draw a line from the bottom edge of the girder at the end, to the bend near the point $a$, to represent the direction which the line of stress in this lower flange endeavors to take between these two points.

Through the reverse bend at the point $m$, draw a line perpendicular to this line, and call this the normal to the assumed line of stress. Knowing the horizontal stress in the flange between the end and the point $m$, we deduce the stress in the direction of the normal which is developed by the horizontal stress. By calculation we determine the normal stress in this case to be 150 000 pounds. Now, this stress is theoretically applied at the point of the bend. Practically from the shape of the flange at this point it must initially be distributed over a very short distance. Let us assume that it may be distributed over as much as 4 inches of distance along the flange.

The material to resist this normal stress is mainly the section through the vertical leg of the 6 inches by 6 feet by $\frac{1}{2}$-inch angles of the angle at the root—this would give us as the resisting section 4 inches by 1-inch across the grain of the material to resist 150 000 pounds, or a stress of 37 500 pounds per square inch, the ultimate strength of material under such conditions.

Assuming that this stress commences to part the vertical from the horizontal leg of the angle, we see that at the instant the part commences, we have at this point only the section of the vertical leg of the angle remaining as flange material proper, whose net section is about 5 square inches.

Now, at this point the material being under tension, and the bearing strength of the rivet connection being superior to the tensile strength of the material, we shall have an increase of stress on the bearing section of the rivets until the tension stress is uniformly distributed over all the material available for tension, or until failure occurs in the bearings.

In other words, we have as the material available for tension the material in the vertical leg of the flange angles = 5 square inches plus one-sixth of the web section = $1\frac{1}{2}$ square inches; total, $6\frac{1}{2}$ square inches to resist the horizontal stress at this point, 284 000 pounds, or 43 700 pounds per square inch, which is a fair average ultimate strength of plate and angle in the direction of the grain.

The bearing stress on the rivets in the stress transmitted to the 5 square inches of section in the vertical leg of the angles = 43 700 pounds × 5 = 218 500 pounds on 3½ square inches of bearing, or 62 430 pounds per square inch, which is about the usual resistance developed under such conditions. Briefly reviewing, we find that only a small portion of the flange section at the point of rupture (5 square inches out of 17 square inches net section) was utilized in resisting flange stress, and that the balance was lost from use on account of the direction given to the flange in the design. We can only say that the stress on the web plate and rivet connection was close to the breaking limit as determined by such experiments as have been made on full-sized built girders and on detail pieces.

Albert Lucius, M. Am. Soc. C. E. —The fact that in this particular experiment the chord angles gave way at a comparatively low strain, and that the web and the riveting stood comparatively such high strain, has been made more of than is warranted by this very inconclusive experiment. The floor beam was acknowledged to be of bad shape, and under test it failed at the bend in the lower chord, near the end of the beam, where it was most likely that it would fail, and it stood between three and four times as much load as it was exposed to in service. The chord angles gave way primarily by the horizontal flange shearing off from the vertical flange, and the latter and the web then broke. This shearing was due partly to the shape of the girder and the sharp bend and offset so near the end, and partly it may have been due to a flaw induced by the bending, or originally in the angles. The experiment sheds no light on this question. The high resistance to shearing and buckling in a shallow and stout web, and the high resistance of riveting especially done for a test-piece are also results not to be wondered at.

Charles O. Brown, M. Am. Soc. C. E.—The form of floor beam under discussion is one that bridge engineers dislike, and consequently try to avoid. It was adopted in this case probably for the purpose of obtaining increased central depth without encroaching upon the waterway. Any person at all accustomed to looking at ironwork would point out the section at *m* (using the designations upon Mr. Boller's diagram) as the weak place. Here the lower flange is bent and the strain being obliged to follow the bend, cannot do so without producing a down pull upon the web and a tendency to separate the horizontal flange of the angle from the vertical flange, and this at a point where the structure of the angle iron has been weakened by heating and bending. It is a well-known fact that bending of large size angles will frequently cause such separation.

With a new bridge, of recent construction, there should be no discussion as to whether it will bear the traffic imposed. The existing standard specifications allow an ample margin for safety, and the question in this case is simply whether the design of these floor beams

complies with such standard specifications. There is no need of any test; analysis of strains will show it.

Taking Mr. Boller's figures (without adding for impact—allowing that to be taken care of by the low-working stresses fixed in specifications) the shearing strain in end section of web plates is 8 000 pounds per square inch. This would be twice the working strain allowed by standard specifications. The actual strain per square inch, after deducting rivet holes is 9 500 pounds or 2.4 times the working stress. The chord strains to be transmitted from *m* through ten rivets is 80 000 pounds or 8 000 pounds per rivet, this again is twice the working stress. These are two points of only one-half the strength that a good structure should have. The beam, if tested, should show a factor of safety of seven, or it should stand before failure a test load of 1 120 000 pounds. It did resist, according to record of test, a little over one-half that load, when it failed at a place which theory and experience points out as the weakest.

Mr. Boller's deductions from the experiment are:

*First.*—That a plate web is an exceedingly stiff member.

*Second.*—That our method of proportioning rivets is wrong.

*Third.*—That the friction due to power riveting has enormous value.

These statements, if intended to allay the fears of the railroad officials or the public, with reference to that "unsafe floor beam," will pass; but when they are brought before the Society, I wish to enter my protest. The friction is too uncertain a quantity to be relied upon, and the experiment certainly shows nothing that would warrant an increase of working strains on web plates, or of the bearing pressure of rivets.

The whole discussion shows conclusively that the knowledge on the subject is sufficiently thorough, and that our standard specifications are safe. So that by the exercise of due care and vigilance in designing and manufacturing we can avoid "unsafe floor beams," and unreliable structures in general.

Theodore Cooper, M. Am. Soc. C. E.—The author having, to his own satisfaction, proved that the accepted practice in designing plate girders is all wrong, it may be well for those whose experience and observation in this field have led them to other conclusions, to protest against so broad a claim being based upon a crude test of a single girder, even should an analysis of this single test hold out the claims.

There is hardly a single fallacy advanced by the ignorant pretenders in the science of engineering that has not been supported by evidence even stronger than that presented in this case.

The application of our accepted rules for designing girders does not show this girder to be a dangerous one under the proposed testing. It does, however, show that the girder is a badly proportioned one.

Does this test prove anything more than this?

The true measure of the strength of a girder is the strength of its

middle section, and a properly designed girder should have its details so proportioned that this maximum strength can be realized.

This girder, as shown by the author, gave way by rupture of the ends before the center flange areas were strained to one-half their full strength, showing very clearly that the ends which should have been the stronger, had only half the needed strength.

I think, therefore, we may conclude from this test, that better results would have been obtained if the "accepted practice in designing plate girders" had been applied to the design of this one. Let us now examine whether the test has proved in any manner that our theories are wrong.

In proportioning plate girders we now determine the number of rivets to be used, upon the basis of the theoretical strains in each part, with certain allowances for shearing strain on the rivets and for the bearing or crushing area of the web plates.

The test shows that the rivets have not sheared nor the webs been torn out in the manner called for by the theory. But we must take other things into consideration. It is well known that the frictional resistance of the rivet heads is very large. Mr. Considère found by a series of experiments that before there was any slipping of plates riveted together this frictional resistance amounted, on an average, to 18 000 pounds per square inch of rivet area, and that it amounted to about 42 000 pounds per square inch of rivet area before actual rupture.

English and American practice has not allowed for such frictional resistance in proportioning the rivets, as there was no certainty how long it would continue after structures were subject to actual service. The general practice of depending upon the shearing resistance and bearing areas and not on this uncertain frictional resistance, has seemed more justifiable.

This girder, made especially for test, was not likely to have any defective workmanship in its construction. The frictional resistance of the newly-driven rivets was undoubtedly high and prevented the rivets acting either by shear or crushing.

Does a girder like this, fresh from the workmen's hands, represent the condition of a similar girder which has been hammered over for years by heavy and rapidly moving trains, with all the conditions of good, bad and indifferent tracks?

I should regret to find that any one had accepted the conclusions of the author that "all formulas for proportioning plate girders are utterly in the fog," and "the dicta of one expert is as good as that of another."

Rule of the thumb designing may be good enough for those who are loath to advance beyond their early practice.

The advances that have been made in recent years in bridge and girder designing have been due to the better consideration of the pro-

portioning of the details and a crude test of this kind will hardly be sufficient to convince us that we are all wrong and "in a fog."

WILLIAM H. BURR, M. Am. Soc. C. E.—A positive determination of the causes of failure of this beam at such an apparently low flange stress at *m*, involves a much clearer knowledge of the action of internal stresses in a plate girder than is at present possessed. If the ordinary methods of plate girder computation be assumed, however, as does Mr. Boller, some very significant results are obtained.

At the instant of failure the flange stress at *m* was 12 600 pounds per square inch (presumed to be on total area). The total sectional area of the two 6 x ½-inch horizontal angle legs at the 14 x ½-inch cover is 19 square inches, which, at 12 600 pounds gives a force of 239 400 pounds. This force, it is to be remembered, does not pass directly into the inclined portion of the flange. As that inclined portion makes an angle to a horizontal line whose sine is 0.537, the force 239 400 pounds has a component normal to the inclined portion of the flange equal to 239 400 × 0.537 = 128 558 pounds. This, it is to be observed, is a force pulling normal to the fibers of the flange angles in the section *m*, and is concentrated at the bend. If it be assumed that it is distributed over 3 inches in length of the two ½-inch thick vertical legs, this normal force will produce a stress per square inch across the fiber of the angle of 128 558 ÷ 3 = 42 852 pounds, which is about sufficient to produce exactly the amount and kind of failure that took place. These figures, of course, have the approximate character which all such computations possess, but no more. They show just why the kind of failure observed took place, although the quantitative determination could not accurately have been made in advance.

In connection with questions of this kind it is seldom or never remembered that every rule for flexure and long column comparison used by the engineer in his daily practice is only loosely approximate, and, strictly speaking, not properly applicable. They can only be correctly applied to beams or columns whose lengths are exceedingly great in comparison with either of their cross dimensions; as they are, and can only be established in the theory of elasticity in solid bodies by making just those assumptions. These rules and formulas, of course, form the basis of all structural computations after empirical quantities, determined by such experiments and tests as that under consideration, are introduced in them, but are essentially valueless for practical purposes until that is done. The author is not far wrong, therefore, in stating that theory applied to such beams leads to very foggy results. Nor is it easy to overestimate the value of such tests as this, for by such means only can the "fog" be dissipated.

After a careful consideration of the results of this test, I cannot find the evidence of the rivet friction which the author of the paper and others believe they find.

ALFRED P. BOLLER, M. Am. Soc. C. E.—While admitting the force of the various comments made upon this experimental girder, which we all agree was of a very bad shape, due to the bend in the lower flange near the ends, all criticisms that had been passed upon it, selected the end web with the connecting rivets as the weakest part, thus determining the strength of the beam. This on theoretical considerations. The fact that the beam failed entirely in the flange under a computed strain (reaction, by distance, divided by depth) comparatively low, before the web was affected with its connecting rivets, is hardly an harmonious agreement between theory and practice, and while perhaps characterizing beam formulas as being "all in a fog" is rather an extreme statement, it would seem in this particular case, the result of the experiment showed a wide gap between theoretical prophesy and actual fact. Nor will it do to brush the experiment to one side as being "crude" and of no importance. It was an actual beam destroyed under pressure, under as fair conditions as it is possible to have—pressures applied by hydraulic power furnished from the testing apparatus of one of our greatest bridge works—and while one may quarrel with gauge readings and absolute values, the relations of the behavior of the several parts of the girder are very clearly recorded. Mr. Devin very ingeniously shows a computation that fairly well fits the experiment after the angle irons had split along the "root," when the tension flange became practically of very small area; but what mode of computation, or what theory could forecast the behavior of that beam had the flange held solid beyond an approximation based upon assumptions. The theory of beams and their flexure is probably as perfect as it ever can be, but, as applied to practice, so many physical and constructive elements come in, that results at best can be but approximations, never exact, involving the exercise of sound judgment quite as much as refined analysis. There is no question, that generally the modern methods of designing and detailing girder work are a vast improvement over even comparatively recent practice, and are all that can be desired so far as safety is concerned, but we must not forget that such work, in the nature of things, is far from theoretical perfection, and should not be used as a basis of condemnation of earlier executed work without very thoughtful consideration. Were theory perfectly applied in practice, there should not be much difference of opinion among expert engineers. But there are many questions that must be settled on pure judgment, and here the dictum of one expert may be just as sound as that of another. Too great a devotion to figures may insensibly affect the judgment, by accustoming the mind to a dogmatic confidence in theoretical conclusions, which, while possibly well enough in new work, becomes a serious matter when applied to work of the past—as fully illustrated by the test and comments on this beam.

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(Vol. XVIII.—May, 1888.)

# SYPHONS OF THE KANSAS CITY WATER WORKS.*

By G. W. PEARSONS, M. Am. Soc. C. E.

PRESENTED FOR ANNUAL CONVENTION OF 1888.

## WITH DISCUSSION.

The first water supply for the Kansas City Water Works was drawn from the Kansas River, one and-a-half miles from its junction with the Missouri; at this place the state line is 700 feet east of the river, the proposed location of the works being in Kansas.

The Water Commissioners fearing complication from this, desired the pumping station to be placed in Missouri if practicable. The nearest available location where drainage could be had for the settling basins was a quarter of a mile, and the conditions such that a syphon was the only available means of reaching the pumping station. The soil is a sandy alluvium, surface 28 feet above low water; about half of the depth can be excavated readily; the lower part, when dug into, shows decided characteristics of quick sand, making a deep trench both difficult and dangerous.

A trench low enough to insure adequate flow at low water was impracticable; a syphon to be safe, must be tight, and to insure this, it must be reasonably accessible.

* These were shown in a description of the Kansas City Water Works, in "Engineering News," November, 1887. The writer has been requested to give a fuller description.

The trench was dug 13 feet deep at the pumping station, 15 feet near the river, descending by an easy vertical curve; the pipe, 24-inch cast-iron, with ordinary lead joints, was laid with care as to grade, so that no air pockets should exist, rising all the way to the well, where it joins a vertical pipe by a tee, with well-rounded angles; the top of this vertical pipe rises 6 feet above the syphon, forming a vacuum chamber; the bottom reaches within 18 inches of the bottom of the well, which is 7 feet below low water in the river, giving an available slope of 5 feet at extreme low water; there are no bends in the line, except such easy curves as could be laid with straight pipe; its delivery is ten millions of gallons in twenty-four hours, with a frictional resistance of 22 feet per mile, or 4.16 feet per thousand.

During high water, the syphon being practically submerged, acts as a conduit, and is controlled by a valve at the pumping station. It was carefully tested as to tightness before filling the trench, but it was found necessary to maintain the vacuum by an air pump attached to one of the engines. This was 3-inch bore, 12-inch stroke, making 18 to 24 strokes per minute, sufficient at first, but within a year it became necessary to aid it by a pipe to one of the condensers. After some five or six years run the air leakage made a reduction in the vacuum in the condenser; the pipe was then dug down to and the joints recaulked, recovering its original tightness; a larger air pump was also put in. In the twelve years of its run, the syphon has never failed, and the only expense attending its use, aside from the working of the air pump, which being attached to the machinery makes no appreciable labor or cost of maintainance, is the recaulking of the joints, which was expensive on account of the depth of the digging required to reach them.

At Quindaro, the new pumping station on the Missouri, it again became desirable to go away from the river for safety. There the syphon is 730 feet long, 42 inches in diameter, cast-iron, lead joints, bottom of pipe trench so soft that it had to be planked to preserve the alignment of the pipe. A steam ejector is used to maintain the vacuum. At present the pipe is so tight that it requires but a few minutes use daily, a vacuum guage being placed in the engine room for the engineers guidance. Rise of syphon (center) 10 feet. The pumping engines at this station have a capacity of one million gallons per hour, not enough to test this syphon to anything like its full capacity, which is probably over 50 millions per day—having an available slope of 12 feet per thousand.

The use of the first syphon showed that while absolutely air tight there was still a sensible amount of air constantly removed by the air pump, showing that it was dissociated from the water; the writer had no means of making quantitative tests, but from observation saw that the amount of air varied sensibly in accordance with the amount of water flowing through the pipe, and that with the full lift of 16 feet the dissociation was much greater than with less lifts—seemingly greater than the difference.

The use of these syphons show that they can be safely depended on in places where it is difficult to lay conduits low enough for direct gravity flow, and that the receiving well which they require is a safe-guard to the syphon in avoiding pulsation or shocks, which would tend to produce air leaks in the joints, and insures the pumps against unequal or undesirable admission of air as well as against the water ram incident to a long suction pipe.

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## DISCUSSION.

A MEMBER.—I want to ask Mr. Pearsons whether the removal of the air from the water makes the water unhealthy?

Mr. PEARSONS.—It does not appear to me that there is a sufficient amount of air withdrawn from the water in its passage through a quarter or an eight of a mile of vacuum line to make any difference. Besides the air thus withdrawn would be very soon restored in the storage basin.

I would say, with regard to aeration, that when the water was passing under the ice of the Missouri River, aeration was beneficial, but that after the river was entirely open and free from ice, I could not find that aeration did any further good.

C. B. BRUSH, M. Am. Soc. C. E.—Was there any smell or taste developed in that water during the summer?

Mr. PEARSONS.—In the upper reservoir, where the water stood still for a long time, there was something of that sort. In our lower basin we do not have anything of the kind, because the water stands in it but a few days.

Mr. BRUSH.—For how long a time was this storage?

Mr. PEARSONS.—About a week in the lower basin.

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(Vol. XVIII.—June, 1888.)

# THE VENTURI WATER METER.*

## DISCUSSION ON PAPER No. 371.

By CLEMENS HERSCHEL, M. Am. Soc. C. E.

Since the experiments of 1887, and since October and December, 1887, when the original paper upon the "Venturi Water Meter" was written for and read before the Society, the meter has made rapid progress. At the present time it constitutes the introduction of a new and pregnant principle into the art of gauging fluids, such as water and other liquids, also steam, compressed air, fuel or illuminating gas, and other gases. The formation of any degree of vacuum, or negative pressure at the throat of the instrument, which first called attention to this method of gauging, has become only a special case of its action, while the measurement of the difference of pressure between the fluid in the main pipe, just above the meter, and as it passes the throat, has been found to constitute a precise measure of the linear velocity, hence of the volume, passing through the throat and through the main pipe.

### DIFFERENCE-PRESSURE GAUGE.

In the discussion immediately following the reading of the paper, it was asked, whether the record of this difference of pressure could be kept automatically, and following the suggestion thus thrown out, I have contrived the difference-pressure recording gauge herewith shown. It is believed that this is the first gauge of this sort ever constructed,

* The Venturi Water Meter. By Clemens Herschel. Transactions, Vol. XVII, p. 228, November, 1887.

barring some attempts to photograph the indications of the two legs of a Pitot tube used in measuring current velocities, and thus to obtain a continuous picture, or record, of the relative positions of the liquid within the Pitot tubes.

A very few words will explain the action of the gauge (Plate XXXIX). $P_1$ and $P_2$ are the two piezometer tubes, the one leading out of the main pipe, just up-stream from the meter, the other leading out of the venturi air-chamber. These are conducted to any convenient point, where is set up the difference-pressure gauge. This swings like a pendulum in stuffing-box bearings, as shown in cross-section Figs. 2 and 3. A diaphragm separates the two pressure conduits, so that the mercury columns, $M_1$ and $M_2$ are respectively acted on through connection pieces, $A_1$ and $A_2$, by the pressure in $P_1$ and in $P_2$. To give more swing to the pendulum, the ball, $B_1$, is the heaviest, and will set the pointer at 0 of the arc, when the two mercury columns are on a level. As soon as any appreciable difference of level is obtained between them, however, due to a difference of pressure in $P_1$ and $P_2$, the gauge will swing away from the 0 of the arc, which can thus be made to indicate directly cubic feet per second or per hour, or any such quantity, passing the meter. The mercury tubes are shown as though made of glass; but this is by no means necessary, as iron or steel will answer equally well. This removes one usual objection to ordinary mercury columns. Another one, that of spilling the mercury by water or steam ram, will not occur in this form of apparatus, I believe: because shocks of this sort, passing the meter, seem to affect both pipes, $P_1$ and $P_2$, simultaneously.

I have tried only one meter as yet under high heads, with an ordinary steam pressure gauge set on $P_1$, and another on $P_2$, and have the belief above expressed in the light of the only experience thus far acquired. That a gauge of this kind can be made to keep its own automatic record need hardly be stated.

Other forms of difference-pressure gauge can, and will no doubt be devised; and upon the construction of very sensitive gauges of this sort depends the perfection of the meter; whose only admitted defect, at present, is its inability to meter very small quantities. Or, in other and more precise words, whose range of capacity is somewhat limited.

A Worthington $\frac{5}{8}$-inch meter, tested in California (Ross E. Browne's Experiments, Van Nostrand's Science Series No. 81), had a range from $\frac{1}{15}$ to 7.5 gallons per minute, or from 1 to 112.5.

A Crown $\frac{1}{2}$-inch meter (tested in New York, 1879) had a range from $\frac{1}{20}$ to about 13. gallons per minute, or from 1 to 338 (nearly). If the least difference of pressure in $P_1$ and $P_2$, above referred to, that can now be measured, be taken at $\frac{1}{4}$ pound per square inch, it would make a range, for the 1-inch meter, spoken of later on, from 1.47 to 31. gallons per minute, or from 1 to 21. If this lowest measure of pressure differences be assumed, however, at $\frac{1}{10}$ of a foot, as was actually done in Ross E.

# Difference Pressure Recording Gauge,

to Accompany

Discussion of Paper No 371.

## "The Venturi Water Meter."

By Clemens Herschel,

M. Am. Soc. C.E.

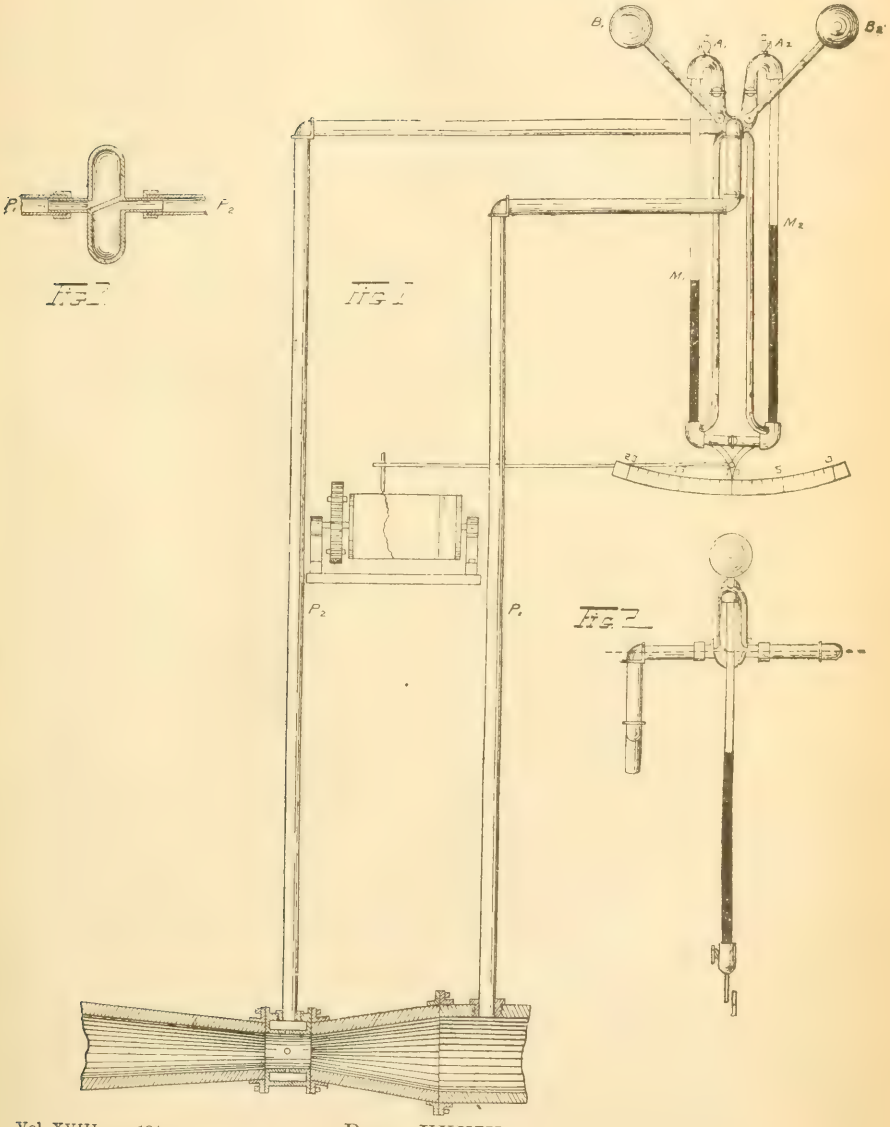


FIG. 2.

FIG. 1.

FIG. 2

Browne's water meter experiments, the above range of capacity would be increased from 1 to 21 to something greater.

And all this only shows that the Venturi meter, from not having been designed for domestic service, does not meet this and other requirements of that particular service. On the other hand, to meter the quantity supplied to large establishments, to a whole district of a city, or to the whole city itself, though that city be of the size of the City of New York, is something that can be done with great ease by the Venturi meter; and it has for such purposes ample range, accuracy and durability, cannot clog up, and keeps well within the practical limits of what such a meter may cost. Other uses of the meter, under low heads, would arise in connection with irrigation works, filtering plants, to meter wash water in industrial works, and water used for power purposes. The meter is also applicable to the gauging of steam, compressed air and other gases.

Generally speaking, a 6 or 8-inch supply pipe limits the size of ordinary water meters, and very few are built, or used, having so much as four inches inlet and outlet; while the Venturi meter is probably unlimited in the size at which it may practically be built and operated, ranging from capillary tubes, to tunnels; but does not meet some of the other requirements demanded of those water meters which are to be used for supplying dwelling houses and other domestic establishments.

## Tests of a One-Inch Meter.

Since paper No. 371 was read before the Society, I have tested a 1-inch meter of the sort therein described, under 210 feet head. The interior of the meter was in outline precisely similar to the other two, already described, but the meter itself was a brass casting, cut to shape and finely polished inside.

Unfortunately there were no facilities at hand to measure pressures accurately. The pressure gauges used were common, cheap, steam-pressure gauges, indicating possibly five or more pounds variance from the truth. Were it not for the fact that their differences alone were used, and that they could always be compared among themselves when the water was still, the results would have been entirely worthless. I submit the table of results which follows, with great diffidence, and only as being better than nothing at all. By reference to what was said concerning the tables given for the 1-foot and for the 9-foot meter, the following table for the 1-inch meter will be readily understood.

## TABLE No. 1.

| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of experiment. | Duration of experiment. | Quantity of water passing venturi. | Velocity through venturi. | Head gauge. Upper. | Head gauge. Lower. | H = Total Head. | | Velocity / Co-eff't = $\sqrt{2gH}$ | Depression gauge. | Working of pet cock. | $H_v$ = Head on venturi. | | Velocity / Co-eff't = $\sqrt{2gH_v}$ | Theoretical $H_v = H \div v$ | Theoretical co-efficient. |
| | min. | Cub. ft. per hr. | Feet per second. | pounds | per | square inch. | Feet. | | pounds per sq. in | | pounds per sq. in | Feet. | | Feet. | |
| 1 | 7.5 | 49.5 | 21.5 | 88. | 87.7 | 0.3 | 0.69 | 3.23 | 86. | Runs Water | 2. | 4.62 | 1.25 | 4.72 | 1.23 |
| 2 | 7. | 80.1 | 34.8 | 86. | 85.2 | 0.8 | 1.85 | 3.19 | 80. | " | 6. | 13.86 | 1.16 | 14.12 | 1.15 |
| 3 | 7. | 100.5 | 43.6 | 85. | 83.7 | 1.3 | 3.00 | 3.14 | 75. | " | 10. | 23.09 | 1.13 | 23.50 | 1.12 |
| 4 | 7. | 117.9 | 51.2 | 84.5 | 82.6 | 1.9 | 4.39 | 3.05 | 70. | " | 14.5 | 33.49 | 1.10 | 34.05 | 1.09 |
| 5 | 6.5 | 142.8 | 62.0 | 82. | 79.1 | 2.9 | 6.70 | 2.99 | 60. | " | 22. | 50.81 | 1.08 | 51.63 | 1.08 |
| 6 | 7. | 170.3 | 73.9 | 81. | 76.9 | 4.1 | 9.47 | 3.00 | 49.5 | " | 31.5 | 72.75 | 1.08 | 73.92 | 1.07 |
| 7 | 7. | 190.0 | 82.5 | 79. | 74.0 | 5.0 | 11.55 | 3.03 | 40. | " | 39. | 90.07 | 1.08 | 91.53 | 1.07 |
| 8 | 5. | 210.7 | 91.5 | 78. | 71.7 | 6.3 | 14.55 | 2.99 | 30. | " | 48. | 110.86 | 1.08 | 112.65 | 1.07 |
| 9 | 5. | 227.5 | 98.8 | 76. | 68.8 | 7.2 | 16.63 | 3.02 | 20. | " | 56. | 129.32 | 1.08 | 131.41 | 1.07 |
| 10 | 5. | 239.4 | 103.9 | 73. | 65.0 | 8.0 | 18.48 | 3.01 | 11. | " | 62. | 143.19 | 1.08 | 145.50 | 1.07 |
| 11 | 5. | 254.4 | 110.4 | 72.5 | 58.5 to 0 | 14. to 72.5 | 32.33 to 167.44 | 2.42 to 1.06 | 2.5 | " | 70. | 161.66 | 1.08 | 164.27 | 1.07 |

It will be observed that no vacuum could be formed in this meter when starting with 88 pounds pressure. But by reducing the head upon the meter, a vacuum just commenced to form, when the other pressures were as given in the following table:

TABLE NO. 2.

| PRESSURE AT HEAD GAUGE. | PRESSURE AT VENTURI GAUGE. | PRESSURE AT A GAUGE DOWN-STREAM FROM THE METER. |
|---|---|---|
| In Pounds per sq. in. | In Pounds per sq. in. | In Pounds per sq. in. |
| 51 | 0 | 38 |
| 41 | 0 | 34 |
| 31 | 0 | 25 |
| 21 | 0 | 15 |
| 11 | 0 | 6 |

PROPER SHAPE FOR THE METER.

The subject of the proper shape for converging and diverging tubes has long occupied the attention of scientists and of mechanics, but owing to lack of experimental data, is yet unsettled. It has been lately treated in a paper by A. F. Nagle, C. E., before the 1888 meeting of the American Society of Mechanical Engineers.

According to the belief therein expressed, at which the author seems to have arrived independently of its suggestion previously by others, the simple rule to be followed is, that the acceleration, or retardation, of the fluid must be uniform, while passing through the converging or diverging tube; being the same idea which was suggested to me in 1874. This produces one form of trumpet-shaped tubes, but leaves the proper length of the tubes undetermined. Least loss of head while passing the meter, must be advantageous, and this would call for as short a length as possible. It is evident that experiment alone can answer some of the questions that arise in this connection. A Venturi meter formed by joining two trumpet-shaped or conical tubes of equal dimensions, at their smaller diameter, would permit of its being used to gauge liquids flowing in either direction, which has a practical value in certain locations; and a refined form of interior lines, should have practical value, in the cases of high heads more especially.

PROPER MODE OF ATTACHMENT, TO THE METER, OF THE PIEZOMETER TUBES.

This has always been a puzzling question to hydraulicians, and the results of many experiments are no doubt worthless or unreliable,

from no other cause than this of faulty attachment or arrangement of piezometers.

The writer means to try whether the mode of attachment originally adopted for the tube leading from the Venturi to its gauge, be not also the proper mode of attachment for the tube leading from any part of the Venturi meter to its appurtenant gauge, and believes that such mode of attachment will give the best results.

### Volumetric Measurements.

In the public mind, when the word water meter is mentioned, there immediately arises the conception of a little cast-iron box, with a set of dials on top, on which may be read off the cubic feet or gallons of water that have passed the meter since the dials last stood at zero. This constitutes a volumetric meter, or integrating meter, as it has been called.

Essentially different from this class are so-called differential meters (carefully to be distinguished from inferential meters, which are only a species of volumetric or integrating meters). Of the differential class, being meters which indicate and measure rates of flow, there are, as yet, in this country, but two kinds—the Deacon waste-water meter and the Venturi meter. Considering now the latter, if it be fitted with any of the ordinary pressure gauges only, it will serve to indicate, by means of a simple computation to be made by the observer, what is the rate of flow through the meter at any moment of observation.

*Second.*—If fitted with the difference-pressure gauge above described, it would indicate directly, on the circular arc of the gauge, the rate of flow in cubic feet, or gallons, per second, or other unit of time, at the moment of observation.

*Third.*—If provided with a self-recording apparatus, it would keep, automatically and continuously, a record of such rate of flow, and would thus furnish the data from which the total volume that had passed the meter between any two intervals of time could be computed.

*Fourth.*—A further step, and one that would convert the differential into an integrating meter, would be to cause the computation last named to be continuously performed and indicated on a train of dials by suitable mechanism, such mechanism being called "mechanical integrators," and many forms of which are in existence. The writer has himself devised one such form, and a very simple one, for the case in hand, and while he has no immediate expectations that a small volumetric meter constructed in this manner can compete with the several simple forms of ordinary small water-meter, yet it is none the less interesting to note that the ordinary volumetric measurement of quantities up to 150 million gallons per twenty-four hours, and even more, is now easily within the compass of a single meter with an accuracy of probably less than $\frac{1}{2}$ of 1 per cent., and at a comparatively very small cost.

Similarly for smaller volumes, from those flowing in 1-inch pipes, or smaller ones, upwards.

The same instrument is also readily arranged to do both kinds of service; to keep a continuous record of the rate of flow, and to indicate on a train of dials the continuous summation of the volumes that have been passing the meter.

## DISCUSSION.

Mansfield Merriman, M. Am. Soc. C. E.—The slight range in the co-efficient, determined by the experiments of Mr. Herschel, show that the Venturi meter gives promise of furnishing a precise method for the measurement of water. It appears to be a form of meter which can not only be used for gauging the flow in mains, but can also be advantageously employed in tests of water motors instead of a weir, particularly in cases where a large number of measurements are to be made. It seems desirable that such a form of tube should be adopted as to give the least loss of head, and the shape used by Mr. Herschel is that which has generally been regarded as giving the maximum discharge, being similar to that regarded as best by Venturi and other experimenters. The tests made by Mr. Francis in 1854 showed that with such a form of tube a maximum discharge of about two and one-half times the theoretic discharge could be obtained, and as no experiments have given a greater ratio it might be inferred that this is the form which gives the least loss of head. In a recent paper before the American Society of Mechanical Engineers, Mr. A. F. Nagle has proposed a form for nozzles and compound tubes which appears theoretically to be more perfect, its sections varying in such a manner that the acceleration is constant. This requirement seems to be the correct one, and can be justified in a number of ways, the simplest being that of analogy from the sections of a jet which rises vertically from an orifice, and attains to the level of the surface of the reservoir. In this case no head is lost, and the acceleration is uniformly decreased, so that a perfect nozzle may be regarded as one whose sections vary in accordance with the same law, frictional resistance being disregarded. To deduce the law of variation of sections let $h$ be the height of the jet and $x$ be any distance above the orifice, and let $d$ and $y$ be the diameter at the orifice and at the height $x$; the corresponding velocities are $\sqrt{2gh}$ and $\sqrt{2g(h-x)}$, and since the velocities are inversely as the areas of the sections,

$$\frac{y^4}{d^4} = \frac{\sqrt{2gh}}{\sqrt{2g(h-x)}}$$

from which the diameter $y$ is

$$y = d\left(\frac{h}{h-x}\right)^{\frac{1}{4}}$$

This is the equation for a perfect jet, in which $y$ becomes infinity when $x$ equals $h$. Now to apply this to the deduction of a form of perfect nozzle let $D$ be the diameter of the large end, $d$ that of the small and $l$ its length. Then $y$ is replaced by $D$ and $x$ by $l$, or

$$D = d\left(\frac{h}{h-l}\right)^{\frac{1}{4}}$$

and eliminating $h$ from the two equations there is found

$$y = d\left(1 - \frac{x}{l} + \frac{x}{l}\,\frac{d^4}{D^4}\right)^{\frac{1}{4}}$$

From this formula values of $y$ may be computed for any assumed values of $D$, $d$, $l$ and $x$, giving a form of curve similar to that shown in the figure. Two of these joined together at the throat may be taken as the Venturi tube of maximum discharge or least loss of head. Theory offers no hint as to the best relations between $D$, $d$ and $l$, but the length of the part below the throat should probably be two or three times that above it.

The following table gives the result of a few computations on the losses of head which occurred in the large meter experimented upon by Mr. Herschel (Transactions, Vol. XVII, page 250). Here $P_1$ refers to the upper piezometer, $P_2$ to that at the throat, and $P_3$ to the lower one. The loss of head given in the third column was directly measured by the difference of the readings of the piezometer $P_1$ and $P_3$; the other columns have been computed from the given velocities and diameters.

| 1. No. of Experiment. | 2. Velocity in feet per second. | 3. Loss of head between $P_1$ and $P_3$. | 4. Loss of head between $P_1$ and $P_2$. | 5. Loss of head between $P_2$ and $P_3$. | 6. Ratio of col. 5 to col. 4. |
|---|---|---|---|---|---|
| 1 | 1.75 | 0.005 | —0.008 | 0.013 | |
| 4 | 4.96 | 0.045 | +0.007 | 0.038 | 5.4 |
| 5 | 7.64 | 0.102 | 0.024 | 0.079 | 3.3 |
| 9 | 10.63 | 0.175 | 0.086 | 0.089 | 1.0 |
| 17 | 22.98 | 0.905 | 0.668 | 0.236 | 0.36 |
| 27 | 29.32 | 1.493 | 1.263 | 0.229 | 0.18 |
| 43 | 32.98 | 1.869 | 1.617 | 0.252 | 0.16 |
| 47 | 34.47 | 2.049 | 1.873 | 0.176 | 0.09 |

This table shows that where the velocity was low the loss of head mostly occurred below the throat, while the reverse was the case for high velocities. It may be thought that in the latter event the stream, after passing the throat, did not touch the sides of the tube at all, but that it expanded according to the law of nature, its sections increasing as its acceleration uniformly diminished. It would be a matter of much

scientific interest if experiments could be made upon the form of tube which theory indicates as the most perfect.

JAMES B. FRANCIS, Past President Am. Soc. C. E.—The theory of the Venturi tube has been known for a long while, but there have been few practical applications of it. It is said that the Romans knew how to get more water into the pipes in their houses by putting a Venturi tube at the end of the pipe. It is this same principle which Mr. Boyden applied in his diffuser to increase the efficiency of the turbine water wheel, but this is a much wider application and it is entirely new, so far as I know. ~~I expect it will overthrow some of our theories of water flow, though whether all of them, is a question.~~ It remains to be proved by experience what changes may come from the use of this tube; still, I think, it is an entirely new application of the old principle.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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# TRANSACTIONS.

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## TEST OF AN EDISON INCANDESCENT ELECTRIC LIGHTING PLANT.

By JOHN W. HILL, M. Am. Soc. C. E.
READ MARCH 7TH, 1888.

### WITH DISCUSSION.

The writer presumes that all members of the Society are interested in the electric light, if not by direct contact with it as constructors or users, at least from the stand point of speculation as to its actual efficiency, comparative cost and general application; and that any practical information (however meager) in this field, will be acceptable for what it is worth.

The writer pretends to no other knowledge of the subject than that gained from a recent test of an isolated plant, in the discharge of his routine duties as an engineer; but he hopes that the facts presented in this paper, may induce others of the Society better qualified than himself, to analyze the large losses of power and reconcile some of the discrepancies which were developed by the test referred to.

The Union Central Passenger Depot, at Cincinnati, is lighted under a contract with local parties, by an isolated Edison Incandescent Electric Light plant of a nominal capacity of eight hundred 16-candle

power lamps. The plant is owned and operated by the local company, which furnishes the necessary attendants, oil and waste for the motive machinery, and makes the lamp renewals; while the Depot Company owns and operates the boilers, and furnishes the steam to drive the engines. Therefore to the cost of the light service, as rendered in monthly bills by the owners of the electric light plant, must be added the gross cost of the steam consumed by the engines which operate the dynamos, to arrive at the actual cost to the Depot Company of the light.

The general terms of the contract under which the light is furnished, require the owners of the electric plant to develop an illumination the equivalent of gas, at the cost of gas; and further provides, that whenever desired, the Depot Company can make a test for comparative effects and costs of gas and electric light, for a period of sixteen days, using each illuminant for eight consecutive days of twenty-four hours each.

The steady and persistent introduction of arc and incandescent electric lighting, in places where under ordinary conditions the consumption of gas would be large, as railroad stations, hotels and public buildings, is viewed—to say the least—not with any feeling of pleasure by the gas companies of the large cities, and as a rule the exact information upon the actual cost, and the cost relative to gas, of incandescent electric lighting, is not as well known to the public or to gas companies, as it should be at the present time.

Constructors and operators of electric plants no doubt are possessed of full information upon the efficiency and cost of this mode of illumination, and seem disposed to retain this information as a profound secret in which laymen and the public have no interest.

During the month of October, 1887, the writer, by mutual agreement of the Union Central Passenger Depot Company, and the owners of the Edison Incandescent Electric Lighting plant in the station, made an eight-days test of the plant, in which he was assisted by Professor Thomas French, Jr., of the Cincinnati University, and Mr. Charles E. Jones, electrician, of Cincinnati. The former gentleman making the photometric tests of specimen lamps, taken from the fixtures in the building; and the latter, furnishing the galvanometer, and reading the currents required to maintain the specimen lamps under different conditions of pressure. Mr. Jones also made the necessary measurements to determine the resistance of the specimen lamps cold.

The motive power is obtained from two Buckeye high speed automatic non-condensing engines, which drive the dynamos through belts and pulleys on a jack-shaft, and are each of 50 nominal horse-power, and operating at a speed of 230 to 235 revolutions per minute.

In the following table are given the principal dimensions of the engines and the pulleys:

| | East Engine. | West Engine. |
|---|---|---|
| Diameter of steam cylinders | 10.02 inches. | 10.03 inches. |
| Stroke of steam pistons | 14.00 " | 14.00 " |
| Diameter of piston rod | 1.54 " | 1.52 " |
| " pulley fly wheel | 4.529 feet. | 4.555 feet. |
| " driving pulley on jackshaft | 2.497 " | 2.516 " |
| " driving pulley on " | 3.332 " | 3.365 " |
| " dynamo armature pulley | 1.1605 " | 1.187 " |
| Ratio speed of dynamo to speed of engine, | 5.207 | 5.132 |

The current generators consist of two Edison dynamos, each of 300 amperes capacity; each being furnished with a commercial ammeter, to indicate the current (amperes), and a Howell indicator to note the pressure of the current in volts.

The boilers furnishing the steam, three in number, are of the return tubular variety, and each of the following dimensions:

| | |
|---|---|
| Diameter of shells | 42 inches. |
| Length of shells | 12 feet. |
| Number of tubes | 40 |
| Diameter of tubes (outside) | 3 inches. |

Grates, continuous under the three boilers, 43 inches long x 12 feet 7 inches wide.

Gas-house coke is used as fuel for the boilers.

The Edison lamps in continuous service, are all of 16 or 32 nominal candle-power; and are distributed through the depot building, train-shed, omnibus court, and storage rooms and stables of the American Express Company.

The test embraced: (*a*) a careful measurement of the performance and cost of operating the boilers; (*b*) the power developed by the driving engines, and the proportion of that power transmitted to the dynamos; (*c*) the power (electro motive force) of the currents generated by the dynamos; (*d*) the lamp service, taken by eight skilled observers, who made hourly rounds of the portion of the building in their respective charge, and noted the time, location and nominal candle-power, of each lamp in service. (In the train-shed, the lamps were operated in rows, as trains arrived and departed; and these were noted by the number

of the row and intervals in service); (*e*) the photometric test of forty-three specimen lamps, taken from the fixtures in and about the depot building and train-shed; (*f*) the test of specimen lamps, simultaneously for brilliancy and current, to estimate the proportion of electrical energy of the dynamos actually realized in the work of the lamps; and (*g*) a weighing of the positive plates of the voltameters; from the transfer of zinc in which the owners of the electric light plant render the monthly bills for lighting the depot and surrounding premises.

For convenience, the results of the tests are presented under the following heads:

*First.*—Comparative cost of electric light and gaslight for equal effects.

*Second.*—Illuminating power of electric lamps, with changes in the angle of the filament or loop, and potential of current.

*Third.*—Performance of the voltameters and relation of their record to the light actually furnished.

*Fourth.*—Relation of the work of the engines to the work of the dynamos, and relation of the work of the dynamos to the work of the lamps.

*Fifth.*—Notes of explanation of the contents of the tables of observed and calculated data.

### 1. Comparative Cost of Electric and Gas Light.

The feed water was measured to the boilers, in two tight casks, containing at 65 degrees Fahrenheit 880.5 and 869.75 pounds respectively. These were charged alternately from the city mains, and the contents delivered through the feed-pump, to the boilers. The water record consisted of the number of casks consumed, the time required to exhaust each cask, and the temperature of the water, which also was the temperature of the feed to the boilers.

The coke, weighing 40 pounds to the standard bushel, was measured in uniform charges of 150 pounds, and two charges of 300 pounds were delivered to the firemen at each round; and no other or additional coke was permitted on the boiler-room floor, until the previous charges were thrown into the furnaces. The quality of the steam was taken with a very sensitive small Fairbanks' platform scale, graduated to weigh to two ounces, and a James Green United States Signal Service thermometer.

During the test of one hundred and ninety-two hours, or eight consecutive days (6 A.M., October 11th, to 6 A.M., October 19th), there were charged to the boilers, the following quantities:

| | Pounds. |
|---|---|
| Coke to start fires | 782.75 |
| Pine kindling, taken at one-half its weight in coke | 244.62 |
| Coke to operate the boilers eight days | 36 376.00 |

There are two batteries of boilers in the station, which are alternated in service every two weeks; whence the average daily consumption of fuel to start fires is 73.384 pounds; and the average daily consumption of fuel, including coke to operate the boilers, 4 620.384 pounds; and a consumption for the month of October, of 3 580.8 bushels, costing at seven cents per bushel, $250.66.

The consumption of water by the boilers from tank measurements for eight consecutive days, was 32 826.83 gallons; to which should be added, five per cent. for wetting the ashes, cleaning boilers and washing the boiler-room floor (taken from separate tap), or 1 641.34 gallons; making total consumption for eight days, 34 468.17 gallons, or a consumption for the month, of 133 564.15 gallons, costing at nine cents per 1 000 gallons, $12.02.

From the bills rendered the Depot Company by the owners of the electric light plant, for 1886, it seems the cost of light for the month of October, is 0.08615 of the cost for the whole year, and as the steam and consequently the cost for fuel and water will be proportional to the illumination furnished, then the cost of these items per annum will be as follows:

$$\text{Coke}\ldots\frac{250.66}{0.08615} = \$2\,909.53. \quad \text{Water}\ldots\frac{12.02}{0.08615} = \$139.53.$$

Add to this the wages of two firemen, at $45 per month each, or per annum $1 080.

Interest on boiler plant and fixtures, valued at $3 000, at five per cent., $150.

Depreciation of boiler plant, taken at 10 per cent. of valuation, or $300.

When the total cost of the steam per annum becomes $4 579.11.

From the tabulated statement of the lamp service during the eight days of test, the average illumination for the whole time is shown to have been equivalent to 185.15 lights of 16 actual candle-power each;

for which the charge for the interval of time according to the method of rendering bills for incandescent electric lighting would have been,

$$\frac{185.15 \times 16 \times 192 \times 45}{1000} = \$255.95.$$

and the annual charge,

$$\frac{255.95 \times 31}{8 \times 0.08615} = \$11\ 512.55.$$

While it is the intention of the owners of the electric plant to make a charge of 45 cents per 1 000 standard candles of illumination, the bills are not based on the amount of light furnished, but on the deposit or transfer of zinc in the zinc voltameters, the assumption being that the zinc deposit, and consequently the average current passing through the voltameters bears a constant proportion to the total current in the circuit in which the voltameter is placed.

If it were convenient to state the actual amount of light furnished for any given length of time, as a certain hourly average number of 16 or 32 actual candle-power lights, it would be preferable to the present mode of charging for the electric light, but no meter has yet been devised—so far as the writer is aware—which will render an account of the lamps in service, and the average brilliancy (candle-power) of the lamps. If such an apparatus were invented, and could be depended upon to render an account of the lamp service, then its statement for the month (or any other interval of time), would be reduced to an average hourly service in thousand standard candles, and multiplied by the rate per thousand candles, upon which the contract for lighting was based. In this instance the rate is 45 cents per thousand candle-power of effect.

From the tabulated statement of the zinc voltameters the transfer of metal from the positive to the negative plates, for the one hundred and ninety-two hours of trial, in the aggregate, was: 21.829 grams, which, according to the formula of the owners of the electric lighting plant, is multiplied by the constant 17, to obtain the corresponding light furnished in thousand standard candles. (The standard candle, to be understood as burning at the normal rate of two (2) grains per minute, or 120 grains per hour.) From which the cost of the illumination (exclusive of steam) to the Depot Company, becomes: $C = 21.829 \times 17 \times .45 = \$167$ for eight days, or \$647.09 for the month (October), corresponding to an annual charge of \$7 511.20, or a total cost for illumination per annum as follows:

| | |
|---|---|
| Electric Light Company, charge..... | $7 511.20 |
| Cost of furnishing steam to operate the driving engines..... | 4 579.11 |
| | $12 090.31 |

The present price per 1 000 cubic feet for coal gas in Cincinnati is $1.15 and by photometric test, according to the determinations of Professor French, has an illuminating power with a consumption of five (5) cubic feet per hour, of 16.94 standard candles, from which a light of 16 candle-powers would represent a consumption of 4.722 cubic feet per hour, and the cost of an illumination the equivalent of that furnished by the electric light for October would be,

$$C = 1.15 \times \frac{185.15 \times 4.722 \times 744}{1\,000} = \$748.03,$$

and an annual cost, assuming as before, that the light for the month of October represents 8.615 per cent. of the light for the whole year of, $8 682.91 or a net annual saving over the electric light of $3 407.40 corresponding to an increased cost for electric over gas lighting of 39.24 per cent.

If the electric light was charged for at the rate of 45 cents per thousand standard candles of *actual effect*, as the contract for the lighting really allows, then the cost per annum, including the outlay of the Depot Company for steam will be $16 091.66, or $7 408.75 over the cost for coal gas, corresponding to an increased cost of electric over gas lighting for same illuminating effect of 85.33 per cent.

Perhaps it will be more convenient to compare the costs of electric and gas-lighting in the following manner: To the rate of 45 cents per 1 000 candle-power of light furnished by the owners of the lighting plant add the cost (ascertained by trial) of the steam per 1 000 candle-power of light; or,

$$\text{Steam}..... \frac{101.54 \times 1000}{192 \times 185.15 \times 16} \times 100 = 17.85 \text{ cents.}$$

Cincinnati gas is shown to have an illuminating power of 16 candles for an hourly consumption of 4.722 cubic feet, and is sold at $1 15 per thousand cubic feet, hence the cost of an illumination the equivalent of 1 000 standard candles burning at the normal rate,

$$\frac{4.722 \times 1.15}{16} \times 100 = 34 \text{ cents.}$$

Bringing the cost together we have:

Per 1 000 candle-power, Edison electric light.....63 cents.
Per 1 000 candle-power, Cincinnati gaslight.....34 cents.

The average light service, and the average illuminating power of the electric lamps, was a matter of ocular demonstration, while the measurement of the illumination furnished by means of the zinc voltameters, depends upon the shunting of a small decimal (0.001) of the current in any circuit, through the meter connected in that circuit.

2. Illuminating Power of Electric Lamps, with Changes in the Angle of the Filament and Potential of Current.

Subsequent to the test for cost of electric light, a special investigation was made of three 16, three 32, and one 100 nominal candle-power lamps, selected from the specimen lamps tested by Professor French for brilliancy during the economy trial of the plant.

These lamps were tested simultaneously for strength of current and illuminating power; the filaments being placed successively in three positions at an angle of 45 degrees, at an angle of 90 degrees, and parallel with the plane of the photometer bar. The 100 candle-power lamp was tested in one position only, at an angle of 45 degrees to the plane of the bar.

The tests for brilliancy of the specimen lamps were made with a standard photometer from the American Meter Company, Philadelphia, the bar being graduated to give the candles power of the sample lights when compared with a single candle, burning at the normal rate of two grains of spermaceti wax per minute; and in order to diminish the ratio of electric to candle light, and keep the observation box over that portion of the scale, where slight differences of illuminating effect could be easily and safely read, two standard candles were burned, while testing the 16 and 32 candle-power lamps, and three candles while testing the 100 candle-power lamp. The standard light was furnished from imported candles, and the initial and final weights of the candles, and time to seconds, during which they were burned, carefully observed, to arrive at the exact rate of consumption of the spermaceti wax. The normal rate of consumption, as is well known, should be 120 grains per hour or two grains per minute, and the photometric observations were corrected to agree with the observed rate at which the sperm was burned for each test.

The galvanometer used in this test was a very perfect instrument, and was connected in the circuit callibrated for location and read by a very skillful observer.

The measured candle power of the specimen lamps in the following table are the means of the three positions in which the filaments were placed, excepting the 100 candle-power lamp as previously noted.

The potential difference given in the table was taken from the Howell indicator in use with the plant at the station.

COMPARISON OF LAMPS FOR CURRENT.

| | Designation of Lamps. | | | | | | No Mark. |
|---|---|---|---|---|---|---|---|
| | B | D | C | F | A | E | |
| Nominal c. p. | 32 | 32 | 32 | 16 | 16 | 16 | 100 |
| Actual c. p. | 62.44 | 30.90 | 30.16 | 36.33 | 21.10 | 16.36 | 144.75 |
| Potential, Volts | 99 | 99 | 99 | 99 | 99 | 99 | 99 |
| Strength of current, amperes | 1.25 | 1.189 | 1.310 | 0.773 | 0.816 | 0.694 | 2.986 |
| Electrical energy in Watts. | 123.75 | 117.71 | 129.69 | 76.53 | 80.78 | 68.71 | 295.614 |
| Watts, per nominal c. p. | 3.867 | 3.678 | 4.053 | 4.783 | 5.049 | 4.294 | 2.956 |
| Watts, per actual c. p | 1.982 | 3.809 | 4.300 | 2.106 | 3.828 | 4.199 | 2.042 |
| Resistance, cold, Ohms | 143.5 | 156.0 | 135.0 | 239.0 | 224.0 | 241.0 | Not taken. |
| Resistance, hot, Ohms | 79.2 | 83.3 | 75.57 | 128.0 | 121.3 | 142.6 | 33.15 |

The 16 and 32 c. p. lamps were tested October 22, and the 100 c. p. lamp, October 21, 1887.

AVERAGES.

| Nominal c. p. | Actual c. p. | Current amperes. | Watts. | | Resistance. | |
|---|---|---|---|---|---|---|
| | | | Per nominal c. p. | Per actual c. p. | Cold. | Hot. |
| 16 | 24.597 | 0.7610 | 4.709 | 3.377 | 234.7 | 130.63 |
| 32 | 41.166 | 1.2497 | 3.866 | 3.363 | 144.8 | 79.36 |
| 100 | 144.75 | 2.986 | 2.956 | 2.042 | .... | 33.15 |

The resistance in ohms of the lamps hot is expressed as follows:

Let $A$ = strength of current in amperes,
$P$ = the potential difference in volts, and,
$O$ = the resistance in ohms,

then $O = \frac{P}{A}$

The Watts or units of electrical energy required to maintain the brilliancy of the lamps is obtained by multiplying the current by the potential, or $W = A \times P$, where $W$ = Watts.

In the table of averages it will be noted that the Watts per actual candle power of lamps is practically the same for 16 and 32 candle-power lamps, while for the 100 candle-power lamp, the electrical energy per actual candle-power is less than 61 per cent. of the energy required by the smaller or weaker lamps. The relative energy required by the 100 candle-power lamp, agrees with the general assertion of electric light operators that a given illumination costs less with lamps of high than low candle-power. But when we turn to the electrical energy

required to maintain the 16 and 32 candle-power lamps, it seems that in this respect there is nothing in favor of the lamps of higher candle-power, and that it costs just twice as much for one 32 candle-power light as for one 16 candle-power light. Of course the cost of lamp renewals is relatively less, when the given illumination is produced with one-half the number of 32 candle-power lights, because the latter, while lasting no longer in service, costs less than twice as much as lamps of 16 nominal candle-power. The relative cost being about as 50 to 65.

The (*D*) 32 candle-power lamp was tested for current and brilliancy, for different conditions of potential, with the following results:

| Potential. | Amperes. | Candle-power. |
|---|---|---|
| 99— | 1.050 | 23.94 |
| 99 | 1.189 | 31.20 |
| 99+ | 1.268 | 43.89 |

No test was made of the Howell indicator from which the potential was read, and the exact value of the graduations, above and below the normal position of the index (99 volts), is unknown. But the whole range of the scale was supposed to be from 93 to 105 volts, from which it appears that a slight change in the potential—such a change as frequently takes place in the operation of the plant, even with reasonably constant manipulation of the resistance box—there is a very great change in the illuminating power and cost of furnishing the light.

The reduction of the resistance reduces the potential and strength of current, and diminishes the power required to drive the dynamos, and prolongs the life of the lamps; but with a loss in the illuminating effect. So long as the illumination is paid for upon the weight of zinc transferred in the voltameters, there may be no serious objection to the variable resistance and potential, and variation in the actual candle-power of the lamps. But should the light be charged for upon the basis of a given average number of lamps, of a given average candle-power, for a given number of hours, then it might operate against the interests of the consumer, in that he may be paying for considerably more light than he receives.

An observer of a lamp giving 43 candle-power actual effect, could distinguish the reduction, if its power was diminished to 24 candles, but could form no correct conception of the measure of reduction, while the life of the lamp would be greatly prolonged by the change of power, and the cost of producing it diminished from 20 to 25 per cent.

Referring to the table, a comparison of the currents required to maintain the lamps, with constant potential (99 volts), shows that the electrical energy, and consequently the cost, is about the same for weak and strong lights; or while the illuminating power of the lamps steadily diminishes with age (use), the strength of current to maintain its brilliancy is substantially constant. Indeed, it may be shown by the data

of this test that the electrical energy and cost of the light becomes greater with the diminished candle-power, thus:

| Nominal candle-power lamps. | Actual candle-power lamps. | Potential volts. | Current amperes. | Electrical energy. Watts per actual candle-power. |
|---|---|---|---|---|
| 32 (*B*) | 62.44 | 99 | 1.25 | 1.981 |
| 32 (*D*) | 30.16 | 99 | 1.31 | 4.300 |
| 16 (*F*) | 36.33 | 99 | 0.773 | 2.106 |
| 16 (*E*) | 16.36 | 99 | 0.694 | 4.199 |

Upon the whole the average current and electrical energy for the tested lamps is substantially the same as for the new lamps of each candle power, thus:

| | | | | | |
|---|---|---|---|---|---|
| 32 candle-power, | lamp (*B*) new lamp..... | 1.25 | amperes, | 123.75 | Watts. |
| 32 " | lamps average all..... | 1.2497 | " | 123.72 | " |
| 16 " | lamp (*F*) new lamp..... | 0.773 | " | 76.53 | " |
| 16 " | lamps average all..... | 0.761 | " | 75.34 | " |

From which it appears that while the electrical energy and cost of maintaining the brilliancy of the lamp, during its life, is reasonably constant, the cost of the light furnished is in an increasing ratio; or, in other words, while the lamps are new the cost for a given illumination is but one-half of the cost for the same illumination after the lamps have been in service for a few weeks. With gas or kerosene a given constant consumption of the illuminating material furnishes a constant power of light, while a diminished brilliancy of light is always accompanied by a reduced consumption of material and a corresponding reduction of cost; with the electric light of the Edison incandescent system, while the power of the light steadily diminishes with use, the cost increases in a corresponding ratio.

| | | |
|---|---|---|
| Of thirty-three 16 nominal candle-power lamps tested by Professor French, the average brilliancy, when placed at angle of 45 degrees to the plane of the photometer bar, was..... | 16.99 | candle-power. |
| When placed at angle of 90 degrees to the plane of the bar..... | 14.26 | " |
| And when placed parallel with the bar..... | 17.05 | " |
| Of the ten 32 nominal candle-power lamps, the average brilliancy, when placed at an angle of 45 degrees to the plane of the photometer bar, was..... | 41.08 | " |
| When placed at an angle of 90 degrees to the plane of the bar..... | 34.13 | " |
| And when placed parallel with the bar..... | 40.66 | " |

The angle of maximum illuminating power for the filament of an electric lamp is supposed to be 45 degrees to the plane of the photometer bar; but from these tests it seems there is very little difference in the

average effects of the lamps when the filament is placed parallel with or at an angle of 45 degrees to the bar. But with the filament placed flatwise, or at right angles to the bar, there is a loss of illuminating power from 17 to 18 per cent.

The extreme sensitiveness of the lights to slight changes in the potential, or strength of current, was clearly shown during the special test for brilliancy and current, the power of the light frequently changing from 20 to 30 per cent. while taking an observation. To the writer it seems that this range and rapidity of variation in the brilliancy of the light is a dangerous feature of the incandescent lighting system, especially if the light should be applied to any close work as reading, writing, drawing, engraving and similar occupations. For general illumination the fluctuations of candle-power may not form a serious objection; but the hurtful influence to the eye of a light which is rapidly changing in illuminating power, is generally recognized by oculists.

The average illuminating power of the thirty-three 16 nominal candle-power lamps tested for brilliancy, was 16.199 actual candle-power; and for the ten 32 nominal candle-power lamps, 38.637 actual candle-power. From which the 16 nominal candle-power lamps in service during the test of eight days should be increased in the ratio of 1.0124, and the 32 candle-power lamps, 1.2074, for actual illumination furnished.

The general average hourly number of lamps in service, were:

| | |
|---|---|
| Of 16 candle-power lamps | 111.961 |
| Of 32 candle-power lamps | 29.733 |

and reducing the 32 nominal candle-power lamps to an equivalent number of 16 candle-power lamps, and increasing both in above ratios, we have as the actual average hourly light service, 185.15. 16 candle-power lights, costing, as previously stated, for an interval of 192 hours, $268.54.

### 3. Performance of the Voltameters.

The voltameters used by the owners of the electric lighting plant to measure the service to the Depot Company, contain two thin zinc plates attached to the positive and negative poles of the cup; the transfer of the zinc from the positive to the negative plate—for any given length of time—being taken as the difference of weight of the losing plate before and after the interval.

In the following table are given the sums of the losses of zinc between 6 A.M. October 11th, and the same hour October 19th, for forty voltameters, divided as follows:

5 six-light meters.
10 twenty-five-light meters.
21 fifty-light meters.
4 one hundred-light meters.

The light mentioned in the designation of the voltameters, means

nominal 16 candle-power lights, from which the meter capacity of the electric lighting plant at the Union Depot is equivalent to 1.730 lamps of 16 candle-power.

Weight of Zinc Plates of Voltameters.

| | Grams. |
|---|---|
| Six Light Meters (5): | |
| Aggregate weight 5 plates, October 11th | 106.770 |
| " " " 19th | 106.371 |
| Difference | 0.399 |
| Twenty-five Light Meters (10): | |
| Aggregate weight 10 plates, October 11th | 761.005 |
| " " " 19th | 759.118 |
| Difference | 1.887 |
| Fifty Light Meters (21): | |
| Aggregate weight 21 plates, October 11th | 3 068.348 |
| " " " 19th | 3 055.427 |
| Difference | 12.921 |
| One Hundred Light Meters (4): | |
| Aggregate weight 4 plates, October 11th | 1 252.760 |
| " " " 19th | 1 246.138 |
| Difference | 6.622 |
| Total deposit for 192 hours | 21.829 |

During the weighing of the zinc plates of the voltameters, the phenomena (which as the writer was informed is not infrequent) developed, of the positive plate gaining instead of losing in weight; showing an apparent reversal of current for meters Nos. 23, 24, 31, 32 and 39. The custom in cases of this kind, being to take the gain of the plate in weight, as the measure of zinc transferred.

Reducing the total deposit of zinc, for eight days, to the average transfer per second, we have. $\frac{21.829}{192 \times 60 \times 60} = 0.00003158$ gram; corresponding according to accepted authority in such matters (*), to an average current of $\frac{0.00003158}{0.0003392} = 0.0931$ ampere.

The proportion of current through the shunts of the voltameters, is $\frac{1}{1000}$ of the entire current; hence total average current for the time of trial, was.....93.1 amperes

*Practical Electricity, by W. E. Ayrton, F.R.S., pages 11-12.

The average illumination produced, was equivalent to 185.15 lights of sixteen candle-power, and from the record of the voltameters the current per 16 candle-power of actual light, was

$$C = \frac{93.1}{185.15} = 0.50283 \text{ ampere.}$$

It is claimed that the current for a nominal 16 candle-power lamp, is about 0.75 ampere; and that this is correct for average lamps, when the potential difference is maintained at 99 volts, is shown earlier in this paper, where the average for three specimen 16 candle-power lamps of different ages, is 0.761 ampere. But the average illumination of 185.15 16 candle-power lamps, from the observation of the lighting service during the test of eight days, are not average lamps but actual lights of 16 candle-power each; and by reference to the tabular statement upon page 150, it will be seen that while the average current for 16 candle-power lamp is 0.761 ampere, the average illuminating power of the tested lamps was 24.597 candles; hence by proportion the current for a light of 16 actual candle-power, should be, $\frac{16 \times 0.761}{24.597} = 0.495$ ampere; or substantially the same current as found from the transfer of zinc in the voltameters.

Adopting the formula employed by the owners of the Electric Lighting plant, the transfer of zinc in the voltameters was held to represent an illumination during the test of 192 hours, of $21.829 \times 17 \times 1000 = 371.093$ candle-power, or 1 932.77 standard candles per hour; which reduced to lights of 16 candle-power, will be 120.736.

The average lamp service, from actual observation, has been stated as 185.15 lights of 16 actual candle-power; from which it seems that the voltameters accounted for only $\frac{120.736 \times 100}{185.15} = 65.21$ per cent. of the actual illumination. But the strength of current per actual candle-power of light furnished, according to the voltameters, was 0.0314 ampere, and the strength of current per actual candle-power of light, from the special test of lamps for brilliancy and current was, for 16 candle-power lights $\frac{3.377}{99} = 0.0341$ ampere; and for the 32 candle-power lights $\frac{3.363}{99} = 0.0339$ ampere; or a mean of 0.034 ampere for both; hence the voltameters —upon the assumption that $\frac{1}{10}$ per cent. of the total current was shunted through them, and that the accepted rate of transfer of zinc per second per ampere of current (0.0003392 grams) is correct— really accounted for $\frac{0.0314}{0.034} \times 100 = 92.35$ per cent. of the total work of the lamps.

Considering the fact of the test for electrical energy required to maintain the lamps at brilliancy, being made subsequent to the general test

for economy of lamp service and illuminating power of lamps; and that the test (for electrical energy) embraced a small number of specimen lamps, the agreement of the work of the voltameters with the observed service of the plant, is reasonably close.

It seems to the writer, if the rate of 45 cents per thousand standard candles of illumination, as charged by the owners of the Electric Lighting plant, is *bona fide*, that the constant 17, by which the deposit or transfer of zinc in the voltameters is multiplied, is in error; and should be increased in the ratio of $\frac{1}{0.6521} = 1.5335$, or should be 26.07; adopting which as the proper constant, the illumination accounted for by the voltameters, during the test, was the equivalent of $21.829 \times 26.07 \times 1\,000 = 569\,082.03$ standard candles; corresponding to an average hourly service of 185.28 lights of 16 candle-power.

From the work of the voltameters, and the special test of specimen lamps for brilliancy and current, the fact seems to be established, that for average lamps—the electrical energy per unit of light is substantially alike for 16 and 32 candle-power lamps; and the electrical energy per unit of light (candle-power), is practically constant for any given lamp operating under different conditions of potential; that is to say, with a 16 nominal candle-power lamp, yielding with one potential an illumination of 16 candles, the electrical energy is increased or diminished in direct proportion, as the potential and power of the light is increased or diminished. This statement, however, must not be confounded with a previous statement, that as the age (use) of the lamp increases the electrical energy per actual candle-power of the light also increases, and that the total energy for any one lamp does not vary materially between its highest and lowest power of illumination, but must be understood as applying to a given lamp at a given age.

4. Relation of the Work of the Engines to the Work of the Dynamos, and Relation of the Work of the Dynamos to the Electrical Energy realized in the Lamps.

During the five days of the test (October 13th–17th inclusive), while the engines were being indicated for power, the average indicated horse-power—for the day service—was 20.306, and the average illumination reduced to lights of 16 actual candle-power each, was 95.52.

No tests were made for friction of the engines and jack-shafts, but from tests of similar engines and connectors, it is assumed that of the indicated power during the day service the friction losses were as follows:

| | | |
|---|---|---|
| Friction of engine, without load..... | 1.09 | horse-power. |
| " " additional due load. | 0.96 | " |
| " " jack-shaft..... | 0.61 | " |
| Total friction..... | 2.66 | " |

or about 13 per cent. of the indicated power was absorbed by frictional losses, leaving 17.645 horse-power to be transmitted to the dynamos; of this, however, 3.516 per cent. was lost by slip of belts, and the net power actually delivered to the dynamos was approximately 17.02, or expressed in terms of electrical energy 12 696.92 Watts.

The lamp service during the daylight hours is given above as the equivalent of 95.52 lights of 16 candle-power: and the electrical energy per lamp, $3.377 \times 16 = 54.032$ Watts; and the electrical energy represented by the actual illumination was:

$$\text{Watts} = 95.52 \times 54.032 = 5\ 161.136,$$

or of the net work of the driving engines transmitted to the armature of the dynamos, only 40.64 per cent. was realized in the work of the lamps.

No statement could be made of the electrical energy developed by the dynamos during the day service of the plant; from the fact of the ammeters being so constructed that considerable current was produced before the index would move from the zero point, and this additive quantity being unknown, readings of the ammeters below 100 amperes could not be made with any degree of accuracy, and were accordingly omitted in making the record of trial.

The statement of the independent work of the dynamos is therefore of necessity limited to the night service of the plant, when the average reading of both ammeters was over 160 amperes, and the least reading of either, 110 amperes; the indications of the instruments, being accepted as reasonably reliable after the index passed the first graduation (100 amperes), when the unknown strength of current required to start the needle from zero was eliminated.

In the following table are given the average indications of the ammeters, during the night service, from October 13th to 17th, inclusive; corresponding with the intervals when the driving engines were being indicated for power.

STRENGTH OF CURRENT.

| Date. | East Dynamo Amperes. | West Dynamo Amperes. | Total Amperes. |
|---|---|---|---|
| October 13th | 163.330 | 150.000 | 313.330 |
| " 14th | 175.909 | 160.000 | 335.909 |
| " 15th | 166.875 | 181.000 | 347.875 |
| " 16th | 150.000 | 147.500 | 297.500 |
| " 17th | 159.000 | 159.000 | 318.000 |
| Average | | | 322.523 |

The average indicated horse-power during the night service was 70.705, of which the losses by friction are estimated as follows, for each engine:

| | | |
|---|---|---|
| Friction of engine, without load..... | 1.0902 | horse-power. |
| " " additional due load. | 1.7131 | " |
| " " jack-shaft ..... | 0.6092 | " |
| Total friction, one engine..... | 3.4125 | " |
| Total friction, both engines..... | 6.8250 | " |

in round numbers, 9.65 per cent. of the indicated power, leaving 63.88 horse-power to be transmitted to the dynamos—less the slip of belts—3.516 per cent., or 2.25 horse-power; and net work of engines actually delivered to the dynamos, 61.63 horse-power; or, in terms of electrical energy, 45 975.98 Watts.

The work of the dynamos during the night service was carefully observed, with the following results:

| | |
|---|---|
| Average difference of potential..... | 99 volts. |
| Average strength of current..... | 322.523 amperes. |

and average electrical energy..... $322.523 \times 99 = 31\ 929.777$ Watts, plus losses not measured between the dynamos and testing instruments. (The ammeters and volt indicators were closely connected with the dynamos, with no intermediate circuit connections, and the losses must have been trifling).

Of the net power of the engines actually transmitted to the dynamos; $\frac{31\ 929.777}{45\ 975.98} \times 100 = 69.45$ per cent., was realized in the work of the dynamos. This difference of energy, or loss of useful work of over 30 per cent., may be separated into two quantities; that due to friction of the dynamo armatures in their bearings, and that due to the resistance in the field of the dynamos. Allowing 7 per cent. of the reduction of work for the friction of the armatures, then 23 per cent. is absorbed in overcoming the resistance within the dynamo.

The lamps in service during the intervals, when the work of the engines and the work of the dynamos were simultaneously measured, were equivalent to 429.319 lights of 16 candle-power; and the electrical energy represented by the actual illumination was:

$$429.319 \times 54.032 = 23\ 196.96 \text{ Watts;}$$

or of the net work developed by the dynamos:

$$E = \frac{23\ 196.96}{31\ 929.777} \times 100 = 72.65 \text{ per cent.,}$$

was accounted for in the electrical energy of the lights.

Omitting the mechanical losses due to friction of engines, extra friction due to load and friction of jack-shafts, only a trifle over one-half (50.45 per cent.) of the net power transmitted to the dynamos, is actually realized in the work of the lamps; and taking the day and night service together, which, for commercial purposes, is the proper mode of estimating the net efficiency of a plant for artificial illumination; then of the net engine power delivered to the dynamos, but 45.5 per cent. is actually realized in the illumination furnished.

This test was made to ascertain, not particular losses, or causes of loss, but the relative cost of electric and gas lighting, and no other data were taken than enough to determine this question, excepting the special test of specimen lamps (before noted) for brilliancy and current.

The writer is not sufficiently familiar with current literature upon the incandescent electric light to know how favorably the efficiency of this plant as a whole, compares with other plants which have been tested; but he has been assured by others interested in lighting, that this Central Depot plant was of a representative character, and that upon test it would compare favorably with any other isolated Edison plant in similar service. If this is true, then the large losses between the driving engines and the current generators, and between the motive power and the illumination produced, should be the means of stimulating electrical engineers to a remedy; the effect of which will of course be to reduce the cost of producing the light.

Constructors of Edison electric lighting plants are accustomed to estimate eight 16 actual candle-power lights to each indicated horse-power of driving engines; which, if realized in practice, would have a marked effect on the cost and relative economy of incandescent electric lighting; but from this test, the ratio of lamps of 16 nominal candle-power, to each indicated horse-power of engine was

| | |
|---|---|
| For the day service, including October 16th (Sunday) | 4.357 |
| For the day service, omitting October 16th | 4.728 |
| For the night service, including October 16th | 5.547 |
| For the entire daily service (24 hours), including October 16th | 4.952 |
| For the entire daily service (24 hours), omitting October 16th | 5.136 |

It will probably be more accurate to state the number of lamps or lights of 16 actual candle-power per indicated horse-power of driving engines. The average indicated horse-power of engine for the day service, for five days, including October 16th, was 20.306, and the average actual illumination for same time, 95.52 lights of 16 candle-power; and lamps per indicated horse-power:

$$L = \frac{95.52}{20.306} = 4.704.$$

The average indicated horse-power for the night service, including October 16th, was 70.707, and average actual illumination for same time, 429.319 lights of 16 candle-power; and lamps per indicated horse-power:

$$L = \frac{429.319}{70.707} = 6.072,$$

or, for continuous day and night service, 5.388 lamps of 16 candle-power each, per indicated horse-power of engine. From which it will be seen

that, even under the most favorable conditions of load and service for this plant, the number of lamps per horse-power is twenty-five per cent. below the proportion of lamps to power assigned by constructors.

Incidental to the performance of the boilers which furnished the steam for the engines, the following data are given.

| | |
|---|---|
| Non-combustible in the coke | 5.21 per cent. |
| Steam per pound of coke, from and at 212 degrees Fahr. | 8.38 pounds. |
| Steam per pound of coke, from temperature of feed water (65 degrees Fahr.) | 7.266 " |

The efficiency of the steam from thirty-four tests was 0.97564, equivalent to an entrainment of 3.336 per cent. of the total feed water supplied to the boilers.

### 5. Notes of Explanation of the Tables of Data.

The record of the lights in hourly service in and about the Depot building, may for convenience, be divided into (*a*) lights throughout the building, not including the train shed, omnibus court, Smith street cross lights, or American Express building; (*b*) lights in the train shed, omnibus court, cross lights over the railroad tracks west of the station; (*c*) lights in the American Express building.

Lights (*a*) and (*b*) were taken by two sets of observers, day and night, during the eight days of trial. Lights (*c*) were taken for the nights of October 18th, 19th and 20th, and averaged for the trial. Lights (*a*) were read hourly, and averaged for the day service, 6 A.M. to 5 P.M., and for the night service, 6 P.M. to 5 A.M., and for shorter day and night intervals, to correspond with the intervals during which the work of the engines and current generators were being measured. Lights (*b*) were read by rows from the switch-board in the train-shed, for the intervals and total time of service for each night of the test. Lights (*c*) were read for intervals and total time of service each night, and also by hours, from 6 P.M. to 6 A.M.

Tables "A" to "E," inclusive, embrace the lamps in service during the entire trial, in detail as follows: Table "A" contains the record of the day service of lamps in the Depot building, from 6 A.M. to 5 P.M. for each of the eight days of test. Table "B" contains the record of the night service of lamps in the Depot building, 6 P.M. to 5 A.M., for each day of the eight days of test.

Referring to Tables "A" and "B," columns 1 to 14, inclusive, are explained by the headings; column 15, Table "A," contains the average hourly lamps for that portion of the day, 10 A.M. to 5 P.M., inclusive, during which the power of the driving engines was measured; and column 16 contains the average of lamps per hour for the entire day (12 hours). Column 15, Table "B," contains the average of hourly lamps for that

portion of the night, 6 P.M. to 10 P.M., inclusive, during which the power of the driving engines and work of the dynamos were measured, and column 16 contains the average lamps per hour for the entire night (12 hours).

Table "C" contains the lamps in service in the warerooms and stables of the American Express Company, for the dates noted; divided into sub-tables, "C" 1, containing the hourly record of lamps in service; "C" 2, containing the average hourly service, between 5 P.M. and 7 A.M.; and "C" 3, the average hourly service between 5 P.M. and 10 P.M., corresponding with the hours during which the work of engines and dynamos were measured.

Tables "D" and "E" exhibit the lamp service for the eight days of test in the train shed. (This embraces the rows of lights over the railroad tracks, the lights in the lobby at the east end of the shed known as the gate row, the lights in the omnibus court at the easterly entrance of the depot, and the lights along the tracks west of the depot. These lamps are divided into twelve rows or series, and controlled from a single switch-board in the train shed). In recording the service the observer noted the rows and times of opening and closing the circuits on the switch-board; and the tables contain the total time for which each particular series of lamps were in use for each day of the test.

The form of subdivisions of tables "D" and "E" is alike for all. At the head is given the date for which such table is compiled. Column 1 contains the number on the switch-board of the series or row of lamps; column 2 contains the number of lamps in the row; column 3 contains the hours and minutes of service; column 4 contains the lamp hours, and is the product of the lamps in the series multiplied by the hours and decimal of service; column 5 contains the average lamps in service per hour, estimated for the hours between which the respective series of lamps are first lighted and last extinguished. Series 1, 2, 3, 4, 5, 6, 8, 9, 11 and 12 are taken for six hours, series 7 for twelve hours, and series 10 for seven hours.

Table "F" exhibits the total average lamps for the night service, from 6 P.M. to 6 A.M., and brings together the lamps for the depot building, American Express Company building (which is furnished with light from the electric lighting plant), and train shed. The headings of the columns sufficiently explain their contents.

Table "G" exhibits the same data as Table "F," but for the interval of time embraced between the hours of 6 P.M. and 10 P.M.

Table "H" contains the average revolutions of the driving engines, arranged for the day and night service of the plant.

Table "J" exhibits a comparison of the speeds of engines and dynamos for same intervals of time, and shows the slip of belts, or loss of motion between the engine and dynamo pulleys. The contents of the columns will be understood from the respective headings. (Assuming

no slip of belts, the revolution of the dynamo armature should be directly as the diameters of driving and inversely as the diameters of driven pulleys.) The pulleys were carefully measured for circumference with a Chesterman tape, and found to be of diameters as stated earlier in this paper. The speeds given in column 5 of this table are obtained by multiplying the known speeds of engines by 5.207 or 5.132 respectively, and the percentage of engine speed realized by dynamo, column 6 is had by multiplying the values in column 4 by 100, and dividing by the values given in column 5.

Table "K" exhibits the indicated horse-power of the driving engines, arranged for the day and night service of the plant.

Table "L" exhibits the performance of the boilers during certain intervals of the eight days of the trial, divided into two sub-tables, of observed and calculated data.

Table "M" exhibits the calorimeter work for test of the quality of steam furnished by the boilers, and contains the averages of thirty-four observations of weights of steam condensed, water heated by the steam, and initial and final temperatures of water heated; the co-efficient of saturated steam 0.9666 was used to reduce the apparent to the actual evaporation in Table "L."

Table "N" exhibits in parallel columns the indicated horse-power of the engines; average lamps in hourly service for the intervals during which the power of engines was measured; equivalent lamps of 16 nominal candle-power; and number of 16 nominal candle-power lamps per indicated horse-power of engines. The actual 16 and 32 candle-power lamps given in column 4 are taken from the hourly records shown in detail in tables "A" to "E;" and the 32 candle-power lamps are reduced to the equivalent number of 16 candle-power lamps in the ratio of two to one, in accordance with the results given under head of "Illuminating Power of Lamps," wherein it appears that the electrical energy per actual candle-power of the specimen 16 and 32 nominal candle-power lamps tested for brilliancy and current are alike, or 3.377 and 3.363 Watts respectively.

## TABLE "A."

### Hourly Record of Day Lamps.

| Date. | Lamps. Nominal c. p. | Time. A.M. 6 | 7 | 8 | 9 | 10 | 11 | 12 | P.M. 1 | 2 | 3 | 4 | 5 | Average part day. | Average part night. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct. 11. | 16 | 85 | 71 | 94 | 71 | 70 | 80 | 64 | 81 | 90 | 91 | 92 | 126 | ..... | 84.58 |
| " " | 32 | 6 | 5 | 8 | 10 | 7 | 9 | 8 | 9 | 12 | 10 | 12 | 10 | ..... | 8.83 |
| " 12. | 16 | 92 | 73 | 89 | 85 | 83 | 82 | 72 | 69 | 82 | 85 | 87 | 116 | ..... | 84.58 |
| " " | 32 | 6 | 5 | 8 | 10 | 10 | 10 | 8 | 9 | 10 | 10 | 10 | 10 | ..... | 8.83 |
| " 13. | 16 | 91 | 75 | 72 | 73 | 70 | 70 | 66 | 62 | 74 | 78 | 83 | 106 | 81.20 | 76.66 |
| " " | 32 | 7 | 5 | 7 | 9 | 9 | 10 | 7 | 8 | 9 | 9 | 10 | 11 | 9.73 | 8.42 |
| " 14. | 16 | 100 | 68 | 86 | 99 | 86 | 86 | 70 | 61 | 76 | 85 | 85 | 118 | 86.06 | 85.00 |
| " " | 32 | 7 | 5 | 11 | 10 | 10 | 10 | 7 | 8 | 8 | 9 | 10 | 10 | 9.29 | 8.75 |
| " 15 | 16 | 90 | 79 | 83 | 76 | 83 | 79 | 64 | 67 | 80 | 84 | 87 | 111 | 85.51 | 81.92 |
| " " | 32 | 5 | 7 | 9 | 11 | 11 | 12 | 11 | 10 | 9 | 12 | 12 | 10 | 11.36 | 9.916 |
| " 16. | 16 | 87 | 66 | 61 | 39 | 29 | 28 | 28 | 30 | 29 | 29 | 31 | 34 | 29.86 | 40.92 |
| " " | 32 | 10 | 6 | 7 | 6 | 6 | 6 | 5 | 5 | 5 | 5 | 4 | 4 | 4.85 | 5.75 |
| " 17. | 16 | 113 | 76 | 86 | 92 | 78 | 77 | 66 | 63 | 72 | 81 | 87 | 113 | 79.85 | 83.666 |
| " " | 32 | 8 | 7 | 9 | 10 | 10 | 11 | 9 | 10 | 10 | 10 | 10 | 14 | 10.57 | 9.83 |
| " 18. | 16 | 97 | 72 | 80 | 82 | 75 | 82 | 74 | 71 | 84 | 88 | 93 | 142 | ..... | 86.666 |
| " " | 32 | 7 | 6 | 8 | 10 | 10 | 10 | 9 | 10 | 10 | 10 | 12 | 14 | ..... | 9.666 |

## TABLE "B."

### Hourly Record of Night Lamps.

(Exclusive of Train Shed and Express Office.)

| Date. | Lamps. Nominal c. p. | Time. P.M. 6 | 7 | 8 | 9 | 10 | 11 | 12 | A.M. 1 | 2 | 3 | 4 | 5 | Average from 6 to 10. | Average, whole night. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Oct. 11 | 16 | 248 | 231 | 226 | 182 | 138 | 125 | 78 | 76 | 76 | 76 | 74 | 77 | ..... | 133.91 |
| and 12 | 32 | 35 | 34 | 35 | 32 | 23 | 21 | 5 | 5 | 5 | 5 | 6 | 7 | ..... | 17.75 |
| Oct. 12 | 16 | 276 | 256 | 255 | 247 | 214 | 162 | 82 | 78 | 79 | 77 | 78 | 81 | ..... | 157.08 |
| and 13 | 32 | 39 | 38 | 35 | 35 | 29 | 23 | 6 | 5 | 5 | 5 | 5 | 8 | ..... | 19.42 |
| Oct. 13 | 16 | 278 | 231 | 229 | 212 | 182 | 129 | 91 | 77 | 75 | 75 | 73 | 77 | 226.4 | 144.08 |
| and 14 | 32 | 31 | 31 | 31 | 29 | 27 | 21 | 7 | 7 | 7 | 7 | 7 | 7 | 29.8 | 17.666 |
| Oct. 14 | 16 | 252 | 225 | 230 | 209 | 181 | 135 | 84 | 81 | 77 | 77 | 78 | 80 | 219.4 | 142.41 |
| and 15 | 32 | 32 | 31 | 31 | 29 | 22 | 19 | 8 | 7 | 6 | 6 | 6 | 8 | 29.0 | 17.08 |
| Oct. 15 | 16 | 261 | 226 | 222 | 213 | 184 | 149 | 88 | 82 | 79 | 77 | 76 | 80 | 221.2 | 144.75 |
| and 16 | 32 | 29 | 31 | 31 | 31 | 22 | 19 | 5 | 5 | 5 | 6 | 6 | 7 | 28.8 | 16.42 |
| Oct. 16 | 16 | 210 | 220 | 216 | 199 | 176 | 120 | 82 | 81 | 77 | 77 | 77 | 80 | 204.2 | 134.58 |
| and 17 | 32 | 30 | 29 | 29 | 27 | 27 | 19 | 7 | 7 | 7 | 7 | 7 | 9 | 28.4 | 17.08 |
| Oct. 17 | 16 | 277 | 226 | 228 | 217 | 179 | 134 | 86 | 81 | 78 | 77 | 76 | 78 | 225.4 | 144.75 |
| and 18 | 32 | 31 | 30 | 30 | 28 | 22 | 20 | 7 | 7 | 7 | 6 | 6 | 7 | 28.2 | 16.75 |
| Oct. 18 | 16 | 266 | 229 | 157 | 218 | 187 | 142 | 88 | 82 | 79 | 78 | 78 | 81 | ..... | 140.4 |
| and 19 | 32 | 32 | 31 | 31 | 29 | 25 | 20 | 5 | 5 | 5 | 5 | 5 | 7 | ..... | 18.0 |

## TABLE "C."

### American Express Office and Stable Lamps.

Record of Lamps by Hours.

| Date. | Lamps. Nominal c. p. | P.M. | | | | | | | A.M. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3 | 4 | 5 | 6 |
| Oct. 18 and 19 | 16 | 11 | 10 | 2 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 5 | 5 | 5 |
| | 32 | 5 | 7 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 4 |
| Oct. 19 and 20 | 16 | 10 | 10 | 5 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 5 | 2 |
| | 32 | 6 | 7 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 3 | 3 | 3 |
| Oct. 20 and 21 | 16 | 10 | 10 | 4 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 4 | 5 | 2 |
| | 32 | 6 | 7 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 2 | 4 | 4 | 4 |

Between 5 P.M. and 7 A.M.

October 18–19. Average hourly 16 c. p. lamps.....3.215
" 32 c. p. " .....3.291
October 19–20. " 16 c. p. " .....3.194
" 32 c. p. " .....2.263
October 20–21. " 16 c. p. " .....3.125
" 32 c. p. " .....3.402
Average for three nights, 16 c. p. " .....3.178
" " 32 c. p. " .....2.985

Between 5 P.M. and 10 P.M.

October 18. Average hourly 16 c. p. lamps.....4.73
" 32 c. p. " .....3.50
October 19. " 16 c. p. " .....5.46
" 32 c. p. " .....4.05
October 20. " 16 c. p. " .....5.28
" 32 c. p. " .....3.70
Average for three nights, 16 c. p. " .....5.157
" " 32 c. p. " .....3.75

## TABLE "D."

### Record of Lamps. Train Shed.

### All 32 c. p. Lamps.

| October 11th. | | | | | October 12th. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. of Row. | Lamps. | Service. Hrs. | Min. | Lamp Hours. | Average Lamps per Hour. | No. of Row. | Lamps. | Service. Hrs. | Min. | Lamp Hours. | Average Lamps per Hour. |
| 1 | 7 | 3 | 23 | 23.681 | 3.947 | 1 | 7 | 3 | 00 | 21. 00 | 3.500 |
| 2 | 7 | 1 | 33 | 10.850 | 1.808 | 2 | 7 | 2 | 47 | 19.481 | 3.247 |
| 3 | 7 | 4 | 08 | 28.931 | 4.822 | 3 | 7 | 4 | 04 | 28.462 | 4.744 |
| 4 | 6 | 1 | 54 | 11.400 | 1.900 | 4 | 6 | 2 | 35 | 15.498 | 2.583 |
| 5 | 7 | 3 | 04 | 21.462 | 3.577 | 5 | 7 | 3 | 10 | 22.162 | 3.694 |
| 6 | 6 | 0 | 57 | 5.700 | 0.950 | 6 | 6 | 2 | 55 | 17.496 | 2.916 |
| 7 | 6 | 11 | 37 | 69.696 | 5.808 | 7 | 8 | 12 | 14 | 97.864 | 8.155 |
| 8 | 6 | 1 | 38 | 9.798 | 1.633 | 8 | 6 | 3 | 17 | 19.698 | 3.283 |
| 9 | 9 | 2 | 23 | 21.447 | 3.574 | 9 | 9 | 3 | 09 | 28.350 | 4.725 |
| 10 | 7 | 5 | 37 | 39.312 | 5.616 | 10 | 7 | 6 | 17 | 43.981 | 6.283 |
| 11 | 6 | 2 | 40 | 15.996 | 2.666 | 11 | 2 | 6 | 02 | 12.066 | 2.011 |
| 12 | 14 | 4 | 04 | 56.924 | 9.487 | 12 | 14 | 4 | 03 | 56.700 | 9.450 |

| October 13th. | | | | | October 14th. | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. of Row. | Lamps. | Service. Hrs. | Min. | Lamp Hours. | Average Lamps per Hour. | No. of Row. | Lamps. | Service. Hrs. | Min. | Lamp Hours. | Average Lamps per Hour. |
| 1 | 7 | 2 | 41 | 18.781 | 3.130 | 1 | 7 | 1 | 55 | 13.412 | 2.235 |
| 2 | 7 | 1 | 58 | 13.762 | 2.294 | 2 | 7 | 1 | 37 | 11.312 | 1.885 |
| 3 | 7 | 4 | 12 | 29.400 | 4.900 | 3 | 7 | 3 | 53 | 27.181 | 4.530 |
| 4 | 6 | 2 | 34 | 15.396 | 2.566 | 4 | 6 | 2 | 36 | 15.600 | 2.600 |
| 5 | 7 | 2 | 07 | 14.840 | 2.473 | 5 | 7 | 3 | 31 | 24.612 | 4.102 |
| 6 | 6 | 1 | 59 | 11.898 | 1.983 | 6 | 6 | 3 | 45 | 22.500 | 3.750 |
| 7 | 8 | 11 | 38 | 93.064 | 7.755 | 7 | 8 | 12 | 13 | 97.728 | 8.144 |
| 8 | 6 | 3 | 09 | 18.900 | 3.150 | 8 | 6 | 2 | 44 | 16.398 | 2.733 |
| 9 | 9 | 2 | 56 | 26.397 | 4.399 | 9 | 9 | 2 | 58 | 26.694 | 4.450 |
| 10 | 7 | 6 | 31 | 45.612 | 6.516 | 10 | 7 | 5 | 42 | 39.900 | 5.700 |
| 11 | 4 | 5 | 02 | 20.132 | 3.355 | 11 | 4 | 4 | 26 | 17.732 | 2.955 |
| 12 | 14 | 4 | 48 | 67.200 | 11.200 | 12 | 14 | 4 | 33 | 63.700 | 10.616 |

Note.—Row 7 averaged for 12 hours. Row 10 averaged for 7 hours. All others averaged for 6 hours.

## TABLE "E."

### Record of Lamps—Train Shed.

### All 32 c. p. Lamps.

| October 15th. | | | | | | October 16th. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of Row. | Lamps. | Service. Hrs. | Min. | Lamp Hours. | Average Lamps per hour. | No. of Row. | Lamps. | Service. Hrs. | Min. | Lamp Hours. | Average Lamps per hour. |
| 1 | 7 | 2 | 44 | 19.131 | 3.188 | 1 | 7 | 1 | 54 | 13.300 | 2.216 |
| 2 | 7 | 1 | 16 | 8.862 | 1.477 | 2 | 7 | 1 | 02 | 7.231 | 1.205 |
| 3 | 7 | 2 | 29 | 17.381 | 2.897 | 3 | 7 | 3 | 10 | 22.162 | 3.694 |
| 4 | 6 | 1 | 51 | 11.100 | 1.850 | 4 | 6 | 1 | 40 | 9.996 | 1.666 |
| 5 | 7 | 3 | 06 | 21.700 | 3.616 | 5 | 7 | 2 | 36 | 18.200 | 3.033 |
| 6 | 6 | 3 | 44 | 22.398 | 3.733 | 6 | 6 | 2 | 11 | 13.098 | 2.183 |
| 7 | 8 | 11 | 45 | 94.000 | 7.833 | 7 | 8 | 11 | 13 | 89.728 | 7.477 |
| 8 | 6 | 2 | 49 | 16.896 | 3.816 | 8 | 6 | 2 | 04 | 12.396 | 2.066 |
| 9 | 9 | 2 | 38 | 23.697 | 3.949 | 9 | 9 | 2 | 37 | 23.544 | 3.924 |
| 10 | 7 | 6 | 17 | 43.981 | 6.283 | 10 | 7 | 5 | 38 | 39.431 | 5.633 |
| 11 | 4 | 5 | 01 | 20.064 | 3.344 | 11 | 4 | 5 | 29 | 21.932 | 3.655 |
| 12 | 14 | 4 | 05 | 57.162 | 9.527 | 12 | 14 | 4 | 14 | 59.262 | 9.877 |

| October 17th. | | | | | | October 18th. | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| No. of Row. | Lamps. | Service. Hrs. | Min. | Lamp Hours. | Average Lamps per Hour. | No. of Row. | Lamps. | Service. Hrs. | Min | Lamp Hours. | Average Lamps per hour. |
| 1 | 7 | 2 | 10 | 15.162 | 2.527 | 1 | 7 | 2 | 35 | 18.081 | 3.013 |
| 2 | 7 | 1 | 13 | 8.512 | 1.419 | 2 | 7 | 1 | 46 | 12.362 | 2.060 |
| 3 | 7 | 3 | 28 | 24.262 | 4.044 | 3 | 7 | 3 | 46 | 26.362 | 4.394 |
| 4 | 6 | 1 | 51 | 11.100 | 1.850 | 4 | 6 | 3 | 17 | 19.698 | 3.283 |
| 5 | 7 | 3 | 13 | 22.512 | 3.752 | 5 | 7 | 3 | 49 | 26.712 | 4.452 |
| 6 | 6 | 3 | 05 | 18.498 | 3.083 | 6 | 6 | 3 | 48 | 22.800 | 3.800 |
| 7 | 8 | 11 | 45 | 94.000 | 7.833 | 7 | 8 | 11 | 45 | 94.000 | 7.833 |
| 8 | 6 | 1 | 39 | 9.900 | 1.650 | 8 | 6 | 3 | 44 | 22.398 | 3.733 |
| 9 | 9 | 2 | 46 | 24.894 | 4.149 | 9 | 9 | 3 | 05 | 27.747 | 4 624 |
| 10 | 7 | 6 | 06 | 42.700 | 6.100 | 10 | 7 | 6 | 04 | 42.462 | 6.066 |
| 11 | 4 | 5 | 45 | 23.000 | 3.833 | 11 | 4 | 6 | 00 | 24.000 | 4.000 |
| 12 | 14 | 4 | 30 | 63.000 | 10.500 | 12 | 14 | 4 | 57 | 69.300 | 11.550 |

## TABLE "F."

TOTAL AVERAGE LAMPS NIGHT SERVICE—6 P.M. TO 6 A.M.

| DATE. | LAMPS. NOMINAL c. p. | BUILDING. | EXPRESS OFFICE. | TRAIN SHED. | TOTAL. |
|---|---|---|---|---|---|
| October 11 | 16 | 133.91 | 3.178 | ..... | 137.088 |
| " ..... | 32 | 17.75 | 2.985 | 26.266 | 47.001 |
| " 12 | 16 | 157.08 | 3.178 | ..... | 160.258 |
| " ..... | 32 | 19.42 | 2.985 | 31.897 | 54.302 |
| " 13 | 16 | 144.08 | 3.178 | ..... | 147.258 |
| " ..... | 32 | 17.666 | 2.985 | 31.282 | 51.933 |
| " 14 | 16 | 142.41 | 3.178 | ..... | 145.588 |
| " ..... | 32 | 17.08 | 2.985 | 31.397 | 51.462 |
| " 15 | 16 | 144.75 | 3.178 | ..... | 147.928 |
| " ..... | 32 | 16.42 | 2.985 | 29.697 | 49.102 |
| " 16 | 16 | 134.58 | 3.178 | ..... | 137.758 |
| " ..... | 32 | 17.08 | 2.985 | 27.523 | 47.598 |
| " 17 | 16 | 144.75 | 3.178 | ..... | 147.928 |
| " ..... | 32 | 16.75 | 2.985 | 29.795 | 49.530 |
| " 18 | 16 | 140.40 | 3.178 | ..... | 143.578 |
| " ..... | 32 | 18.00 | 2.985 | 33.827 | 54.812 |

## TABLE "G."

TOTAL AVERAGE LAMPS NIGHT SERVICE—6 P.M. TO 10 P.M.

| DATE. | LAMPS. NOMINAL c. p. | BUILDING. | EXPRESS OFFICE. | TRAIN SHED. | TOTAL. |
|---|---|---|---|---|---|
| October 11 | 16 | 205.00 | 5.157 | ..... | 210.157 |
| " ..... | 32 | 31.8 | 3.750 | 45.788 | 81.338 |
| " 12 | 16 | 249.6 | 5.157 | ..... | 254.757 |
| " ..... | 32 | 35.2 | 3.750 | 54.591 | 93.541 |
| " 13 | 16 | 226.4 | 5.157 | ..... | 231.557 |
| " ..... | 32 | 29.8 | 3.750 | 53.721 | 87.271 |
| " 14 | 16 | 219.4 | 5.157 | ..... | 224.557 |
| " ..... | 32 | 29.0 | 3.750 | 53.700 | 86.450 |
| " 15 | 16 | 221.2 | 5.157 | ..... | 226.357 |
| " ..... | 32 | 28.8 | 3.750 | 50.513 | 83.063 |
| " 16 | 16 | 204.2 | 5.157 | ..... | 209.357 |
| " ..... | 32 | 28.4 | 3.750 | 46.629 | 78.779 |
| " 17 | 16 | 225.4 | 5.157 | ..... | 230.557 |
| " ..... | 32 | 28.2 | 3.750 | 50.740 | 82.790 |
| " 18 | 16 | 211.4 | 5.157 | ..... | 216.557 |
| " ..... | 32 | 29.6 | 3.750 | 58.808 | 92.158 |

## TABLE "H."

Speed of Engines—Revolutions per Minute.

| Date. | Time. | East Engine. | West Engine. |
|---|---|---|---|
| October 12 | Day | .. .. | 233.92 |
| " 12 | Night | 225.96 | 230.00 |
| " 13 | Day | 229.60 | ..... |
| " 13 | Night | Counter off | 233.36 |
| " 14 | Day | ..... | 231.84 |
| " 14 | Night | 228.89 | Counter off. |
| " 15 | Day | 229.59 | ..... |
| " 15 | Night | 221.62 | 232.47 |
| " 16 | Day | ..... | 231.96 |
| " 16 | Night | 230.80 | 237.03 |
| " 17 | Day | 229.86 | ..... |
| " 17 | Night | 226.59 | 233.20 |
| " 18 | Day | ..... | 235.68 |
| " 18 | Night | 227.36 | 231.97 |

## TABLE "J."

Comparison of Speed—Engines and Dynamos.

| Date. | Engine. | Revolutions per Min. Engine. | Revolutions per Min. Dynamo. | Theoretical Rev. per Min. of Dynamo. | Percentage of Engine Speed Realized. |
|---|---|---|---|---|---|
| Oct. 12. | West, A.M. | 236.358 | 1 172.0 | 1 212.99 | 96.62 |
| " 13. | East, " | 229.600 | 1 152.0 | 1 195.53 | 96.36 |
| " 13. | West, P.M. | 233.360 | 1 158.57 | 1 197.60 | 96.74 |
| " 14. | " " | 231.840 | 1 159.33 | 1 189.80 | 97.44 |
| " 14. | East, P.M. | 228.890 | 1 137.60 | 1 191.83 | 95.45 |
| " 15. | " A.M. | 230.000 | 1 145.43 | 1 197.61 | 95.64 |
| " 15. | West, P.M. | 232 470 | 1 162.66 | 1 193.03 | 97.45 |
| " 15. | East, " | 221.620 | 1 109.00 | 1 154.00 | 96.10 |
| " 16. | West, A.M. | 231.600 | 1 156.00 | 1 188.57 | 97.26 |
| " 16. | " " | 230.250 | 1 138.66 | 1 181.64 | 96.36 |
| " 16. | East, P.M. | 230.900 | 1 169.66 | 1 202.29 | 97.28 |
| " 17. | " A.M. | 230.460 | 1 145.33 | 1 200.00 | 95.44 |
| " 17. | West, P.M. | 232.57 | 1 165.33 | 1 210.99 | 96 23 |
| " 17. | East, " | 224.82 | 1 128.50 | 1 170.63 | 96.41 |

| | Per cent. |
|---|---|
| Average, East | 96.097 |
| " West | 96.870 |
| Slip of belts, East engine | 3 903 |
| " " " West " | 3.130 |

Note.—Fly-wheel, West Engine, covered with paper.
" East " not " " "

## TABLE "K."

### Indicated Horse-Power of Engines.

| Date. | Time. | East Engine. | West Engine. |
|---|---|---|---|
| | | Horse-Power. | Horse-Power. |
| October 12 | Day | ..... | ..... |
| " 12 | Night | ..... | ..... |
| " 13 | Day | 21.327 | ..... |
| " 13 | Night | 35.975 | 32.888 |
| " 14 | Day | ..... | 22.027 |
| " 14 | Night | 39.701 | 34.008 |
| " 15 | Day | 21.493 | ..... |
| " 15 | Night | 35.863 | 38.076 |
| " 16 | Day | ..... | 13.777 |
| " 16 | Night | 33.425 | 32.586 |
| " 17 | Day | 22.904 | ..... |
| " 17 | Night | 36.377 | 34.624 |
| " 18 | Day | ..... | ..... |
| " 18 | Night | ..... | ..... |

## TABLE "L"

### Performance of Boilers.—Data.

| Date. | Time Starting. | Time Stopped. | Hours Water Measured. | | Tanks Used. | | Total Water. | Total Coke. |
|---|---|---|---|---|---|---|---|---|
| | | | | | No.1. | No.2. | | |
| | A. M. | P. M. | Hrs. | Min. | | | Pounds. | Pounds. |
| October 11. | 9.25 | 7.17 | 9 | 52 | 10 | 10 | 17 502.50 | 2 535.00 |
| " 12. | 7.20 | 7.16 | 11 | 56 | 11 | 12 | 20 133.25 | 2 545.50 |
| " 13. | 7.00 | 5.25 | 10 | 25 | 8 | 7 | 13 121.50 | 1 974.14 |
| " 14. | 7.00 | 9.55 | 14 | 55 | 15 | 15 | 26 253.75 | 3 195.92 |
| " 15. | 7.00 | 5.00 | 10 | 00 | 7 | 7 | 12 251.75 | 1 593.93 |
| " 16. | 7.00 | 9.50 | 14 | 50 | 13 | 13 | 22 753.25 | 2 990.58 |
| " 17. | 8.15 | 5.55 | 9 | 40 | 8 | 7 | 13 121.50 | 1 973.64 |
| | P. M. | A. M. | | | | | | |
| " 18. | 2.00 | 1.00 | 11 | 00 | 13 | 12 | 21 872.75 | 2 602.90 |

ECONOMY.—STEAM PER POUND OF COKE.

| DATE. | Apparent Evaporation. | Actual Evaporation. | Temp. Feed Water. | Evaporation from and at 212° Fahr. |
|---|---|---|---|---|
| October 11 | 7.023 | 6.788 | 67.0 | 7.811 |
| " 12 | 7.909 | 7.645 | 66.5 | 8.801 |
| " 13 | 6.646 | 6.424 | 65.8 | 7.400 |
| " 14 | 8.215 | 7.941 | 64.0 | 9.161 |
| " 15 | 7.686 | 7.429 | 64.2 | 8.569 |
| " 16 | 7.608 | 7.354 | 63.7 | 8.493 |
| " 17 | 6.648 | 6.426 | 62.6 | 7.422 |
| " 18 | 8.403 | 8.122 | 62.6 | 9.381 |
| Average | | 7.266 | | 8.380 |

## TABLE "M."

QUALITY OF STEAM.—CALORIMETER.

| | |
|---|---|
| Average steam condensed, pounds | 12.763 |
| " water heated, " | 200.00 |
| " initial temperature, Fahr | 62.42 |
| " " " corrected | 62.43 |
| " final " Fahr | 129.34 |
| " " " corrected | 129.66 |
| Range | 67.23 |
| Heat units per pound of steam | 1 183.174 |
| Average steam pressure, pounds | 80.057 |
| Heat units at observed pressure | 1 212.720 |
| Difference | 29.546 |
| Latent heat of steam | 885.590 |
| Percentage of water entrained | 3.336 |
| Efficiency of steam | 0.97564 |

## TABLE "N."

### Comparison of Power and Lamps.

| Date. | Time. | Horse-Power. | Lamps. | | Equivalent 16 c. p. Lamps. | 16 c. p. Lamps per H. P. |
|---|---|---|---|---|---|---|
| | | | 16 c. p. | 32 c. p. | | |
| October 13. | Day. | 21.327 | 81.20 | 9.73 | 100.66 | 4.719 |
| " 13. | Night. | 68.863 | 231.557 | 87.271 | 406.099 | 5.897 |
| " 14. | Day. | 22.027 | 86.06 | 9.29 | 104.64 | 4.750 |
| " 14. | Night | 73.709 | 224.557 | 86.450 | 397.457 | 5.392 |
| " 15. | Day. | 21.493 | 85.51 | 11.36 | 108.23 | 5.035 |
| " 15. | Night. | 73 939 | 226.357 | 83.063 | 392.483 | 5.308 |
| " 16. | Day. | 13.777 | 29.86 | 4.85 | 39.56 | 2.871 |
| " 16. | Night. | 66.011 | 209.357 | 78.779 | 366.915 | 5.558 |
| " 17. | Day. | 22.904 | 79.85 | 10.57 | 100.99 | 4.409 |
| " 17. | Night. | 71.001 | 230.557 | 82.79 | 396.137 | 5.579 |

### Lamps, 16 nominal C. P. per Indicated Horse-Power of Engine.

| | |
|---|---|
| Average for day (including October 16th) | 4.357 |
| " " " (omitting " " ) | 4.728 |
| " " night | 5.547 |
| " " day, 24 hours, including October 16th | 4.952 |
| " " " " omitting " " | 5.136 |

## DISCUSSION.

JOHN W. HOWELL, C. E.—The Central Union Depot in Cincinnati is lighted by an Edison Isolated Electric Light plant. The plant is owned by local parties, who operate it and sell the current to the Depot Company, the Depot Company supplying steam and the owners of the plant supplying the lamps.

The contract between these parties gives the Depot Company the privilege of lighting the depot for one week of each year with gas, and if this week's lighting costs less than the following week's lighting by electric light, then the price of electric light must be reduced in like proportion.

About two years ago the Depot Company lighted their depot with gas for one week and with electric light for one week, as specified in the contract. This test was conducted by the Depot Company themselves, and the results showed that lighting by electric light cost them 40 per cent. less than lighting by gas.

In October, 1887, the Depot Company had another comparison made, the entire conducting of the test being placed in the hands of the Cincinnati Gas Company. I went to Cincinnati to look after the interes of the Electric Light Company, but was unable to secure any information as to the test proposed. The owners of the electric light plant were not recognized in this test; I therefore withdrew and watched the proceedings.

Previous to the test, the electric light plant was shut down for eight days and the depot lighted by gas; the Gas Company keeping a number of men on the watch to see that due economy was observed in the use of the gas. For the next eight days the depot was lighted by electricity, the owners of the electric plant merely seeing that the same economy as to light was observed as during the preceding test. The cost of the electric light during those eight days was 10 per cent. less than that of the gas during the previous eight days. Consequently the owners of the electric light plant were not required to reduce the price at which they furnished the light.

These tests furnished a direct comparison between the cost of lighting a given building with gas at $1 15 per 1 000 feet and with electric light. The same amount of light was required in both cases, and all conditions were the same.

I think that it is to be regretted that the comparison instituted by Mr. Hill was not based on the actual result financially of these tests, instead of on the relative illuminating power of gas and incandescent lamps.

A few words in explanation of the small number of lamps per horse-power shown by the test. The parties installing this depot plant, to

secure themselves against accident, put in two engines and countershafting, which enables them to use either engine to run the dynamos. This largely increases the friction, and the friction of the shaft is a practically constant quantity. Owing to the rigid economy used in burning the lamps during the test, the power measurements were taken with first, only about one-eighth load on the dynamos and second, with very little over half a load on; this not only puts the dynamos under its worst conditions of economy, but the large shaft friction being charged against a very small load, makes a very bad showing for the lamps. With the same lamps and dynamos used in Cincinnati, with a good load the Edison Company has often guaranteed eight lamps of sixteen candles for each horse-power delivered to the dynamos. This guarantee has been frequently tested and has never been disproved. The Edison Company now sells lamps and dynamos with which it guarantees twelve lamps of sixteen candles each for each horse-power delivered to the dynamos. This guarantee has been tested at two plants and in both cases the full number of lamps guaranteed was obtained. The first of these tests was made at Lowell by the company owning the water-power there, they using their own dynamometer and making the test themselves. The second test was made at the Toledo, O., State Asylum by State experts.

In both cases the results showed a small margin above the guarantee —both showed over twelve lamps per horse-power delivered to the dynamos. Mr. Hill gives two measurements of horse-power and lamps, the first one about four and three-fourth lamps to the horse-power, with one-eighth load on the dynamo, and the second five and three-fourths, with half load. Full load on the dynamos ought to get seven or more. The larger the load on the dynamo the smaller the proportion of the total load is friction and the better the result. It is against the practice of the Edison Company to use shafting between the engine and dynamos. They always belt direct from engine to dynamo; this reduces the friction to a minimum. With a full load on the dynamo the friction of the engine and dynamo will be about 20 per cent. of the total load; with one-eighth of the load I would expect 40 or 50 per cent. of the total to be friction. In an engine running with one-eighth of its load what would the friction be? What per cent. of the total?

Mr. Hill notes a very great loss of energy between the engine and the electric light circuit, and it is due to this loss that the number of lamps per horse-power is so small. This loss is made up of two parts, the loss in the dynamo and friction. There have been a great many tests of dynamos published, all of which show the losses in dynamos to be very small. Losses by friction in engines and shafting are exceedingly variable, and depend entirely upon the condition of the bearings at the time. Mr. Hill assumes the loss by friction, and by inference charges the remaining loss to the dynamo. Considering the very great

uncertainty of losses by friction, and the ease with which it could have been measured, the assumption seemed decidedly unscientific.

There is one other point. Where Mr. Hill speaks of the great variation in the light given by incandescent lamps, when making measurements of the candle light of the lamps, he gives the variation as 20 per cent., and he does not attempt to give any reason for it. There is only one thing that can make the lights vary, and that is the variation of the pressure on the line, and there are very few things that will make that vary; either very great changes in the load or in the speed of the engine. I am very well satisfied that the changes in the lights were due to changes in the speed of the engine. Any change in the speed of an engine will make the lights go up or down, as the case may be. When making measurements, if there are sudden changes it is undoubtedly due to changes in the speed of the engine. We all know that an electric light is steady; we know that its steadiness depends upon the steadiness of the speed of the dynamo. Latterly electric lighting has developed a type of engines that give better results than ever before. It is necessary in electric lighting to have a steady speed, and I think the alarm over the danger of variation in the electric light is not at all warranted. I think that in a large majority of cases they give a very steady, uniform light.

As a lamp gets older it takes less power to run it, but it gives less light; the reduction in light is faster than the reduction in power necessary to run it; it takes more power per unit of light as the lamp gets older, but the lamp requires less power to run it.

John W. Hill, M. Am. Soc. C. E.—The writer was engaged to make the investigation by the executive officer of the Depot Company, and was informed, prior to beginning work, that his selection was reported to and approved by the officers of the Electric Company. If Mr. Howell, as he states, was present during the test, the writer can only regret that he did not make himself known and give him (writer) the benefit of his knowledge and experience in these matters.

All of the data touching the cost of producing the light by the Edison system were taken jointly by one set of observers under direction of the writer, and another set under direction of the Electric Lighting Company, and he is not aware that any exception by the Electric Lighting Company has ever been taken either to the methods employed in making the test or in the accuracy of the data as reported.

While it is true that the distribution of the indicated horse-power of the engines is not as accurate as it could have been by means of special tests (before or after the general tests) for friction of engine, jack shaft and dynamos—which tests, in passing, it is well to remark, were not admissible, owing to circumstances beyond my control—the main elements of the question, however, were carefully measured, *i. e.*, the power developed by the engines and the electrical energy developed in the lamps.

The steam engine indicators were in perfect working order, and the springs carefully tested for these experiments. The assistants in charge of the engine test were experienced and careful men. The motion of the engines was taken with reliable, continuous counters, Schaffer & Budenberg make. The apparatus for the photometric tests was well constructed and worked by Professor French, with extreme accuracy in view; while the galvanometer was said to be one of the most perfect instruments in the country, and the readings were taken by a skillful electrician after a careful calibration in the test circuit to reconcile the effect of local disturbances.

While it may be true that more of the loss between the engines and lamps should be charged to the engine and connectors and less to the current generator, the main fact which I wished to emphasize remains unchanged, viz.: of the indicated power of the engines, which power is a direct and exact measure of the cost of producing the light, only 40 per cent. is realized in the illuminating effect of the incandescent lamps.

It would no doubt be very interesting to know how this loss of about 30 per cent. is divided up, but no opportunity was afforded to do so in this test.

The frictional loss in modern automatic engines and jack and line shafts has been so fully investigated by experimenters (the writer among others), that no serious mistake should be made in apportioning the power so expended under known conditions of service.

The plates of the zinc voltameters were weighed by an employee of the Edison Light Company in my presence, and his determinations accepted as correct.

The tests for quality of gas furnished by the Cincinnati Gas Company were made by Professor French of the Cincinnati University; and the tests for brilliancy of the electric lamps were made by Professor French, Mr. C. E. Jones (a local electrician), and the writer, and I am quite sure the prejudices of these gentlemen (if they had any) were in favor of the electric light.

There was a test with gas for eight days with the following results:

| | | |
|---|---|---|
| Cubic feet of gas consumed | 214 700 | |
| Cost at $1 15 per 1 000 cubic feet | | $246 90 |
| Average actual candle-power of the gas, for a consumption per hour of five cubic feet, as measured by Professor French | 16 94 | |
| Average lights of 16 candle-power per hour for eight days | 236 81 | |
| Cost per light of 16 actual candle-power for eight days | | 1 04 |

From the test of the electric lighting plant, the data of which is all in the writer's possession, and for the accuracy and fairness of which

he personally vouches, there were as average effects for the eight days of the test, the following:

| | |
|---|---|
| Cost of lights as per the rate paid by the Union Depot Company to the Edison Electric Light Company (not including the cost of furnishing the steam to operate the driving engines) | $167 00 |
| Cost of the steam, including all items of expense, which is borne by the Depot Company | 101 32 |
| Total cost for eight days | $268 32 |
| Average hourly illumination by the electric light plant in lights of 16 actual candle-power each for eight days | 185 15 |
| Cost per light for eight days | 1 45 |

From which, by the simple rule of three, is deducted the increased cost of electric lighting over gas lighting of more than 39 per cent.

The comparative cost of the two distinctive modes of lighting was not based on theory.

The only facts in connection with gas which it is necessary to know to institute a comparison of cost, for equal effects of illumination, are the candle-power of the gas (which in this instance, as has been stated in the paper, was carefully measured by Professor French), and the cost of the gas per thousand cubic feet, which is $1.15 net. Having these data, the comparison of cost can be made practically.

The writer was not present during the test of lighting the Depot Building with gas, and the quantity consumed during the eight days was communicated to him by the President of the Gas Company, General A. Hickenlooper, and the quality of the gas furnished by the Gas Company during the test of eight days was reported to him by Professor French, and he has no reason to question the accuracy of either. But assuming that the statement of the quantity of gas consumed is incorrect, this has no influence on the comparison of costs; the value of the gas, in candle-power, and its cost per 1 000 cubic feet, are all the data required to make such a comparison. Taking the actual data of the eight days' test with gas, and comparing with the data given in the paper, we have by a different method of stating the case the same relative results.

In regard to the superfluity of shafting, of which Mr Howell complains, there is one counter shaft between the engines and the dynamos (and I think this is the usual arrangement employed with similar plants), to increase the speed from 230 at the engine to 1 150 at the dynamos.

The engines were built by the Buckeye Engine Company, of Salem, O., which concern has had considerable experience in constructing engines for electric lighting plants, and these were rated at a maximum

capacity of 50 indicated horse-power each, and were operated during the test of eight days with an average load of 30.34 indicated horse-power each, or at three-fifths of the rated capacity, and not one-eighth, as Mr. Howell put it, the load on the engines being five times his assumption. The cylinders are 10 inches diameter, 14 inches stroke, and the engines, as stated above, operated at a nominal speed of 230 revolutions per minute.

The fluctuations in candle-power of the lamps while under photometric test, I supposed at the time, were due to variations in the speed of the engines driving the dynamos, but as this variation seems to be unavoidable with driving engines as at present constructed, I cannot see how an apology for the defects of the engine is calculated to diminish this vicious and altogether objectionable feature of incandescent lighting. As to the merit of the writer's opinion on the injurious effect of an unsteady light or of rapid fluctuations and wide range of candle-power in any lamp upon the organs of vision, he who doubts its correctness is respectfully referred to any experienced occulist. I have taken the liberty of asking General Hickenlooper to give me a written statement of his knowledge of the motive of this investigation, and to correct or explain such matters in the discussion as were calculated to impair the scientific value of the facts presented in the paper.

The substance of his reply is appended as part of this discussion.

A. Hickenlooper.—Some of the statements by John W. Howell with reference to the competitive test of gas and electric lighting at the Grand Central Depot in Cincinnati, do not accord with my recollection of the facts.

*First.*—As regards the statement that the Depot Company made a test two years ago, and found that lighting by electricity cost 40 per cent. less than lighting by gas.

The fact is that the Electric Light Company made the test, and neither the Gas Company nor the Depot Company had anything to do with it. The result of the test as published by the Electric Light Company was that, on an eight night test, the gas cost $497 28, and the electric light $343 29. This test was made during the eight longest nights of the year.

At the same rate per night, this would make gas lighting for the year cost $22 703 94, but in fact the Gas Company did light the depot for one year at a cost of $5 892.

The cost of the electric light last year was $14 664 12.

The statement that the last test in October, 1887, was made entirely by the Gas Company, is not correct. It was entrusted to the experts, John W. Hill and Professor Thomas French.

As to the cost of the last test, the records show that for electric lighting the cost was—

| | |
|---|---|
| For steam service | $102 03 |
| The meters showed a consumption at contract rate of | 167 00 |
| Total | $269 03 |

while the same degree of illumination by gas required the use of 167 801 cubic feet, at $1 15 = $192 97.

The total gas used on the premises during the gas test, was 196 700 cubic feet, at $1 15 = $226 20.

The conclusions regarding relative cost were not arrived at by taking the theoretical cost in either case. The actual cost of lighting by both gas and electricity was used.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

# TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

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(Vol. XVIII.—June, 1888.)

## FORMULAS FOR THE WEIGHTS OF BRIDGE TRUSSES.

By A. J. DU BOIS, Jun. Am. Soc. C. E.

PRESENTED AT THE ANNUAL CONVENTION, JULY 2D, 1888.

In the Society Transactions for May, 1887, Vol. XVI, page 191, the writer presented a series of rational formulas for plate girders and truss spans, which gave rise to valuable discussion.

As regards the formula for trusses then presented, the results of the discussion may be fairly summed up as follows:

*First.*—The formula presented, was considered as too complicated, required too much labor to use, and was not sufficiently accurate to justify its use as a guide in practice, or as a basis of estimates of cost.

*Second.*—The method by which the strut formula was introduced was criticised as unsound.

*Third.*—It was objected that no proper provision was made for details, such as lattice bars, pins, eye-bar heads, etc.

*Fourth.*—It was asserted that a general rational formula which should include all the styles of truss in use, and while giving accurate results still be sufficiently simple for practical use, was in the nature of things, impossible.

While, therefore, the formula was very generally admitted to be valuable, and more accurate than any previous formula making claim to

rationality, the general opinion seemed to be that it was itself so largely empiric, as to justify its being classed as such. Therefore theoretic deductions from it could not be safely trusted, while its accuracy was not sufficient to pay for the trouble of using it in cases where a close estimate was desired. Hence a simpler empiric formula would better answer every practical purpose.

Now from the last conclusion, that a general rational formula, accurate and sufficiently simple, is impossible, I expressed then, and wish to express now, strong dissent. I was able to see no reason why this problem, which is daily solved in particular cases, should not admit of a general solution, and as no such reason was given by any one in the discussion referred to, I am still unable to conceive upon what grounds the attempt is considered beforehand as a hopeless one, unless, indeed, it be the conceded fact that no one has thus far succeeded in it.

The outline of the method of attack I adopted was as follows:

The strain in each member of the truss was found in general terms, for any depth, $d$, span, $l$, number of panels, $N$, and loading, precisely in the same way as in any special case. The unit stress, modified for struts as usual, was then introduced and the area of each member found. The introduction of the strut formula here was one of the points called in question. The area of each member thus found multiplied by the length, gave the contents, and the weight was thus easily found. My formula contained but two empiric constants and gave good results over a wide range.

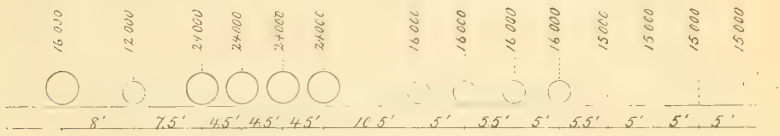
Still the first three objections which I have enumerated have caused me to devote further attention and much labor to the problem, and the belief that I have successfully met them is my excuse for this paper.

I believe that the perfected formula which I now wish to present, practically meets all the objections noted. It is thoroughly rational, simple, and easy to use, general in application to different styles of truss, accurate enough for an estimate, and hence of value in deciding between different styles, dimensions, etc. I have inserted the strut formula in a manner which seems free from objection and have taken proper account of details and secondary bracing. These are large claims, and I make them plainly in order to invite criticism and engage the labor of others in order to substantiate them, if true, or expose them if false. The great value such a formula would have, if these claims stand the test, is beyond question; and that they will therefore be very thoroughly tested I have no doubt.

Live Load.—The first step in the problem is to assume the live load for which the truss is to be designed. I assume two "typical locomotives" with tenders, followed by a train load of 3 000 pounds per foot, as given by Mr. Pegram in his paper, Transactions for February, 1886, Volume XV.

I assume this train load to be applied by concentrated loads of 15 000 pounds at every five feet.

Of course any live load desired may be assumed. I take the preceding, both for purposes of illustration and because I believe it to be such a loading as meets the requirements of present and future practice. A sketch of this loading is given here.




In determining the strains in the members, I have found that it leads to too much complication to work out the strains due to live and dead loads separately. In order to avoid such complication, I have taken the strains for a uniform load only. This, while correct enough for the flanges gives too little for the web. In order to meet this defect I suppose the truss covered with an equivalent uniform load, that is, such a uniform load as would cause at the center of the span a moment equal to the greatest moment at that point due to the actual assumed load system.

I denote this equivalent uniform load per foot per truss by $w_1$.

Our first step then is to make out, once for all, a table giving the value of $w_1$ for our assumed load system, for different spans. This is easily done for any desired system. In the table which follows we give the values of $w_1$ for the two typical locomotives and train load already described. Those wishing to use the formula for any other system of loads must of course make out such a table for the system assumed. It is only necessary to find the maximum moment at the center in foot pounds, and divide eight times this moment by the square of the span in feet. The excellent method by slide and diagram, described by J. E. Greiner, C. E., in the *Engineering News*, April 14th, 1888, affords a swift and accurate means of finding the maximum center moment for any system of loads whatever.

TABLE No. 1.

Equivalent Uniform Load $w_1$, per Foot per Truss, on the Basis of Assumed Load System, for Single Track. For Double Track, take Double Values. Span in Feet, $w_1$ in Pounds.

| Span = | 50 | 55 | 60 | 65 | 70 | 75 | 80 | 90 | 100 | 110 |
|---|---|---|---|---|---|---|---|---|---|---|
| $w_1$ = | 1 848 | 1 733 | 1 718 | 1 677 | 1 618 | 1 570 | 1 546 | 1 552 | 1 560 | 1 569 |

| Span = | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 190 |
|---|---|---|---|---|---|---|---|---|
| $w_1$ = | 1 579 | 1 586 | 1 574 | 1 562 | 1 556 | 1 546 | 1 533 | 1 516 |

| Span = | 200 | 210 | 220 | 230 feet and over. |
|---|---|---|---|---|
| $w_1$ = | 1 511 | 1 506 | 1 502 | 1 500 pounds. |

The table gives $w_1$ for one truss, on the assumption of two trusses to the bridge.

Dead Load.—Our next step is to find all the dead load exterior to the truss itself. This consists of the rails, ties, planking, spikes, etc., of the cross-girders and stringers, and of the wind bracing.

All these quantities are independent of style of truss, and are capable of accurate and independent estimate. For railway bridges, a usual estimate for rails, ties, planking, spikes, etc., is 400 pounds per foot, or 200 pounds per foot per truss, if there are two trusses. For highway bridges, a separate estimate must be made for each case, according to circumstances.

The weight of cross-girders and stringers can be easily estimated for any assumed live load and panel length whatever may be the style of truss. Let us call the weight per foot per truss of rails, ties, etc., and of cross-girders and stringers, $w_2$. A table for $w_2$ can easily be filled out once for all. We give such a table for illustration.

Any designer or bridge company has the materials at hand for filling out such a table according to their own practice. The table we give here has already been given in our previous paper.

## TABLE No. 2.

### For Railway Bridges.

Weight $w_2$ per Foot per Truss, of Floor, Stringers and Cross-Girders, for Single and Double Track, for Assumed Load System. Rails, Ties, etc., taken at 200 pounds per Foot per Truss. Iron Plate Girders for Stringers and Cross-Girders.

| Panel Length in Feet. | Single Track—15 Feet Wide. | | | | Double Track—25 Feet Wide. | | | |
|---|---|---|---|---|---|---|---|---|
| | Weight of One-half Cross-Girder. | Weight of One Stringer. | Rails, Ties, etc., at 200. | $w_2$ | Weight of One-half Cross-Girder. | Weight of One Stringer. | Rails, Ties, etc., at 200. | $w_2$ |
| 5 | 507 | 188 | 1 000 | 339 | 1 555 | 376 | 2 000 | 786 |
| 6 | 582 | 248 | 1 200 | 338 | 1 783 | 496 | 2 400 | 780 |
| 7 | 631 | 315 | 1 400 | 335 | 1 935 | 630 | 2 800 | 766 |
| 8 | 679 | 386 | 1 600 | 333 | 1 992 | 772 | 3 200 | 745 |
| 9 | 695 | 463 | 1 800 | 327 | 2 135 | 926 | 3 600 | 740 |
| 10 | 716 | 545 | 2 000 | 326 | 2 192 | 1 090 | 4 000 | 728 |
| 11 | 750 | 657 | 2 200 | 328 | 2 291 | 1 314 | 4 400 | 727 |
| 12 | 776 | 825 | 2 400 | 333 | 2 374 | 1 650 | 4 800 | 735 |
| 13 | 806 | 974 | 2 600 | 337 | 2 443 | 1 948 | 5 200 | 738 |
| 14 | 831 | 1 130 | 2 800 | 340 | 2 540 | 2 260 | 5 600 | 743 |
| 15 | 853 | 1 292 | 3 000 | 343 | 2 606 | 2 584 | 6 000 | 746 |
| 16 | 872 | 1 460 | 3 200 | 345 | 2 664 | 2 920 | 6 400 | 748 |
| 17 | 886 | 1 634 | 3 400 | 348 | 2 700 | 3 268 | 6 800 | 751 |
| 18 | 906 | 1 816 | 3 600 | 351 | 2 775 | 3 632 | 7 200 | 755 |
| 19 | 930 | 2 003 | 3 800 | 354 | 2 841 | 4 006 | 7 600 | 760 |
| 20 | 949 | 2 197 | 4 000 | 357 | 2 871 | 4 394 | 8 000 | 763 |
| 21 | 968 | 2 420 | 4 200 | 361 | 2 957 | 4 840 | 8 400 | 771 |
| 22 | 983 | 2 652 | 4 400 | 365 | 3 004 | 5 304 | 8 800 | 777 |
| 23 | 1 001 | 2 900 | 4 600 | 369 | 3 030 | 5 800 | 9 200 | 783 |
| 24 | 1 018 | 3 133 | 4 800 | 373 | 3 080 | 6 266 | 9 600 | 789 |
| 25 | 1 034 | 3 382 | 5 000 | 376 | 3 128 | 6 764 | 10 000 | 795 |
| 26 | 1 048 | 3 633 | 5 200 | 380 | 3 172 | 7 266 | 10 400 | 801 |
| 27 | 1 062 | 3 904 | 5 400 | 384 | 3 213 | 7 808 | 10 800 | 808 |
| 28 | 1 077 | 4 180 | 5 600 | 387 | 3 282 | 8 360 | 11 200 | 816 |
| 29 | 1 086 | 4 463 | 5 800 | 391 | 3 332 | 8 926 | 11 600 | 822 |
| 30 | 1 104 | 4 756 | 6 000 | 395 | 3 373 | 9 512 | 12 000 | 829 |

For other widths than those assumed in the table, we may easily change the weight of one-half cross-girder, which is the only item affected, by multiplying by $\frac{\text{width}}{15}$ or $\frac{\text{width}}{25}$.

So also the values for rails, ties, etc., may be changed to correspond to any special case, if the allowance of 200 pounds per foot is not satisfactory. If the stringers or cross-girders, or both, are of wood, the corresponding values can easily be found. In short, it is, I think, evident, that tables giving $w_2$ accurately, may easily be drawn up, in accordance with any specifications and any variety of circumstances. Our Table No. 2, will serve not only as an illustration of what is meant, but also will, we believe, give good values of $w_2$ for standard specifications, and best practice of to-day.

We have thus far, then, found and tabulated $w_1$ and $w_2$. It remains to estimate the weight of wind bracing, $w_3$. Here, again, tables should be drawn up giving the actual results of practice. In place of such tables we venture to submit the following simple empiric formulas, which we have found quite accurate over a wide range of cases. We do not propose these formulas as better than the tables alluded to. The actual results of practice are, of course, preferable. The formulas for $w_3$ are as follows:

### Formulas for Estimating Weight per Foot per Truss of Wind Bracing for Railway and Highway Bridges.

For pony trusses, depth below 12.5 feet:

$$w_3 = 1.8\ N + \frac{270}{p}$$

Through trusses, upper and lower horizontal bracing only. Depth between 12.5 and 24 feet:

$$w_3 = 3.2\ N + \frac{336}{p}$$

For through or deck trusses, with vertical sway bracing, depth above 24 feet:

$$w_3 = \frac{3\,Nl}{170} + \frac{568}{p}$$

$N$ = number of panels; $l$ = span in feet; $p$ = panel length in feet.

We have thus far, we trust, made it clear that all the dead load, exclusive of the truss itself, admits of easy and accurate determination, without any calculation whatever, by simple inspection of properly prepared tables, which can be drawn up once for all, independent of the truss. This external load admits of such endless variation, especially in the case of highway bridges, that it would be, indeed, a hopeless task to attempt to include it in any rational formula. It is, we believe, just this attempt which has rendered all such formulas heretofore worthless.

For railway bridges we have, then, for dead load, two tables and a set of formulas for wind bracing. It is open to any one who takes exception to either to replace them by others. We believe the values given will be found accurate enough for estimates upon the basis of any of the best standard specifications.

### Weight of Truss.—Demonstration of Formula.

We now finally arrive at the truss itself. Let the weight per foot of the truss be $w_4$ pounds per foot, due to the actually supporting members, and let $w_6$ be the weight per foot of the lattice bars, pins, eye-bar heads,

splice plates, etc.; in short, everything not actually supporting. It is evident that if we can find $w$ and $w_0$ accurately, the problem is solved. Thus, the total weight of iron in the bridge, exclusive of course of shoes, roller plates, etc., is $2\,(w_2 - 200 + w_3 + w_4 + w_0)$. We have already disposed of $w_2$ and $w_3$. The 200 subtracted is for the rails, ties, etc., included in $w_2$.

Let us take, as an illustration of our method of dealing with the truss, a Warren girder of span $l$, and panel length $p$, load on bottom chord as the simplest case. Let the number of panels be $N$. The load at each lower panel point is then $(w_1 + w_2 + w_3 + w_4 + w_0)\,p$, where $w_1$ is the equivalent live load per foot; $w_2$, the floor; $w_3$, the wind bracing; $w_4$, the truss proper; $w_0$, the details, all per foot per truss. For brevity let us call this $W\,p$.

The end reaction is then $\dfrac{W(N-1)\,p}{2}$.

The strain in the first lower panel is the reaction multiplied by $\frac{p}{2}$ and divided by the depth, $d$. If this strain is divided by the stress per square inch for tension $R_t$, we have the area. The area multiplied by $p$ gives the volume, and this by $\frac{1}{3}^0$ gives the weight for iron. We have thus for the weight of the first lower panel

$$\frac{10\,Wp^3}{12\,R_t\,d}\,[N-1]$$

In precisely similar way we find the weight of each lower panel, as follows:

| | | | |
|---|---|---|---|
| Weight of first lower panel, | $\dfrac{10\,Wp^3}{12\,R_t\,d}$ | | $[N-1]$ |
| " " second " | | " | $[3\,(N-1)-2]$ |
| " " third " | | " | $[5\,(N-1)-8]$ |
| " " fourth " | | " | $[7\,(N-1)-18]$ |

Summing up the series we have for the weight of the whole lower chord,

$$\frac{5\,WNp^3\,(N^2-1)}{18\,R_t\,d}$$

Dividing by $l = Np$, we have the weight per foot $\dfrac{5\,Wp^2\,(N^2-1)}{18\,R_t\,d}$. In precisely similar manner we have for the upper chord the weight per foot per truss $\dfrac{5\,Wp^2\,(N^2-1)}{18\,R_c\,d}$, where $R_c$ is the unit stress for compression.

For the ties, in like manner, we easily find $\dfrac{5\,W\,(p^2+4\,d^2)\,N}{24\,R_t\,d}$, and for the struts $\dfrac{5\,W\,(p^2+4\,d^2)\,N}{24\,R_c\,d}$.

Adding these four quantities we have for the total weight per foot of one truss, exclusive of the details, $w_4$,

$$w_4 = \frac{5\,W}{18\,d}\left[\frac{(N^2-1)\,p^2}{R_t} + \frac{(N^2-1)\,p^2}{R_c} + \frac{0.75\,(p^2+4\,d^2)\,N}{R_t} + \frac{0.75\,(p^2+4\,d^2)\,N}{R_c}\right]$$

For the sake of brevity let us put $T=(N^2-1)\,p^2+0.75\,N(p^2+4\,d^2)$ $C=(N^2-1)\,p^2$, $S=0.75\,N\,(p^2+4\,d^2)$, where $T$ refers to the tension members, $C$ to the upper chords, and $S$ to the struts.

Placing for $W$ its value, we have now

$$w_4 = \frac{5\,(w_1+w_2+w_3+w_4+w_5)}{18\,d}\left[\frac{T}{R_t}+\frac{C}{R_c}+\frac{S}{R_s}\right]$$

From this we have

$$w_4 = \frac{w_1+w_2+w_3+w_5}{\frac{3.6\,d}{\frac{T}{R_t}+\frac{C}{R_c}+\frac{S}{R_s}}-1}$$

Thus far, it will be observed, everything is entirely rational. We have, it is true, considered the truss as uniformly loaded with the full load. This gives somewhat too little for the ties and struts, the maximum strain in which is caused by a varying position of the live load. To balance this we have taken $w_1$ as the equivalent uniform load, thereby getting somewhat too much for the flanges.

Now the strut formula for the upper chords may be written $R_c = \frac{\mu}{1+\frac{p^2}{250\,r_1^2}}$, and for the struts, $R_s = \frac{\mu}{1+\frac{p^2+4\,d^2}{4\times 125\,r_2^2}}$, $p$ and $d$ being in feet. The numerator $\mu$ is usually taken for iron at 8 000.

Inserting these values of $R_c$ and $R_s$, we have the weight of the truss alone, exclusive of details,

$$w_4 = \frac{w_1+w_2+w_3+w_5}{\frac{3.6\,\mu d}{\frac{\mu}{R_t}T+C+S+\frac{Cp^2}{250\,r_1^2}+\frac{S\,(p^2+4\,d^2)}{500\,r_2^2}}-1}$$

Now the unit stress for tension $R_t$ is on the average about the same as $\mu$. We can without appreciable error, therefore, put $\frac{\mu}{R_t}=1$.

For the square of the radius of gyration for the chords, $r_1^2$, I find that the simple expression $\frac{(N-1)\,p^2}{100}$ gives very close values when compared with actual practice. For the struts we take $\frac{(N-1)}{50}$ multiplied by the square of the length, or in this case, $\frac{(N-1)\,(p^2+4l^2)}{200}$. This is our first introduction of anything empirical. These simple expressions give, we believe, the values of $r_1^2$ and $r_2^2$ with all desirable accuracy.

Inserting them we have

$$w_4 = \frac{w_1 + w_2 + w_3 + w_0}{3.6\,\mu l} - 1 \qquad \ldots\ldots\ldots(1)$$
$$\alpha p^2 + \beta l^2 + \frac{\alpha p^2 + 4\,\beta l^2}{5\,(N-1)}$$

where $\alpha = (2\,N^2 + 1.5\,N - 2)$ and $\beta = 6\,N$ for Warren girder.

For single intersection Pratt truss, we should have

$$\alpha = (2\,N^2 + 3\,N - 2) \text{ and } \beta = 3\left(2\,N - 4 + \frac{11}{N}\right)$$

For double intersection Whipple truss,

$$\alpha = 2\left(N^2 + 3\,N - 10 + \frac{12}{N}\right) \text{ and } \beta = 3\left(N - 2 + \frac{16}{N}\right)$$

For any style of truss the values of $\alpha$ and $\beta$ are easily made out once for all. They are the co-efficients of $p^2$ and $l^2$ given in our previous paper for the value of the quantity we there called "$A$." A comparison of (1) with the formula for $w_4$ given in that paper, will show a marked difference in two respects. First, $w_0$ did not occur in that formula. Second, in place of the term

$$\frac{\alpha\,p^2 + 4\,\beta\,l^2}{5(N-1)} \text{ we had } \frac{45\,p^2 + 202\,l^2}{(w_1 + w_2 + w_3)\,p}$$

It will be seen that we now have varying constants $\alpha$ and $4\,\beta$, in place of 45 and 202, and the details are now included in $w_0$.

Here, then, we have in (1) a formula, entirely rational, made out by the same statical principles which would be employed in the solution of any special case, and following step by step the method of special calculation. We have also introduced the strut formula, thereby allowing for the increase of section required by long struts. It only remains to find the value of $w_0$, or the weight per foot of lattice bars, eye-bar heads, pins, splice plates, etc.

Value of $w_0$.—We have thus far made no attempt to fit our formula to any special cases, the only empiricism being in the introduction of the radius of gyration. In the discussion upon my previous paper Mr.

Pegram gave the weights of a 255.5-foot span for different depths and panel length.

Making use of his data we have applied formula (1) and determined what $w_0$ should be, provided the formula is in all other respects correct. The results are as follows:

| | | | | |
|---|---|---|---|---|
| For $N=14$, $p=18.25$ | | | | |
| $d=$ | 29 | 32 | 35 | 38 |
| $w_0=$ | 118 | 132 | 150 | 164 |
| For $N=10$, $p=25.55$ | | | | |
| $d=$ | 29 | 32 | 35 | 38 |
| $w_0=$ | 116 | 126 | 136 | 145 |

It will be observed that in the first case, the difference is 14 pounds for every three feet of depth. The panel weight for one foot of depth, or the weight of details per foot of depth is then $\frac{14}{3} \times 18.25 = 85.16$ pounds.

In the second case we have a difference of 10 pounds for every 3 feet of depth. The weight of details per foot of depth is then $\frac{10}{3} \times 25.55 = 85.16$ pounds, or precisely the same, just as it should be.

Does not this indicate that the formula is correct?

Now from this case of 255.5-foot span alone I deduce for $w_0$ the empirical formula $w_0 = \frac{Nd}{3} + A$

where $A$ depends only upon the number of panels, and is given by

$$A = 0.875\,N\,(12-N)+6$$

This last value can be tabulated, and we thus have the following table:

TABLE No. 3.

$$w_0 = \frac{Nd}{3} + A.$$

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $N=$ | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| $A=$ | 34 | 36.6 | 37.5 | 36.6 | 34 | 29.6 | 23.5 | 15.6 | 6 | −5.37 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $N=$ | 14 | 15 | 16 | 17 | 18 | 19 | 20 |
| $A=$ | −18.5 | −33.4 | −50 | −68.4 | −88.5 | −110.4 | −134 |

Our values of $\alpha$ and $\beta$ also can be tabulated as follows:

TABLE No. 4.

VALUES OF $\alpha$ AND $\beta$.

| $N$ | Single intersection. | | Double intersection. | | Warren. | |
|---|---|---|---|---|---|---|
| | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ | $\alpha$ | $\beta$ |
| 2 | 12 | 16.5 | 12 | 24 | 9 | 12 |
| 3 | 25 | 17 | 24 | 19 | 20.5 | 18 |
| 4 | 42 | 20.25 | 42 | 18 | 36 | 24 |
| 5 | 63 | 23.6 | 64.8 | 18.6 | 55.5 | 30 |
| 6 | 88 | 29.5 | 92 | 20 | 79 | 36 |
| 7 | 117 | 34.714 | 123.428 | 21.857 | 106.5 | 42 |
| 8 | 150 | 40.125 | 159 | 24 | 138 | 48 |
| 9 | 187 | 45.666 | 198.666 | 26.333 | 173.5 | 54 |
| 10 | 228 | 51.3 | 242.4 | 28.8 | 213 | 60 |
| 11 | 273 | 57 | 290.1818 | 31.3636 | 266.5 | 66 |
| 12 | 322 | 62.666 | 342 | 34 | 304 | 72 |
| 13 | 375 | 68.538 | 397.846 | 36.69 | 355.5 | 78 |
| 14 | 432 | 74.357 | 457.714 | 39.4285 | 411 | 84 |
| 15 | 493 | 80.2 | 521.6 | 42.2 | 470.5 | 90 |
| 16 | 558 | 86.0626 | 589.5 | 45 | 534 | 96 |
| 17 | 627 | 91.941 | 661.412 | 47.8235 | 601.5 | 102 |
| 18 | 700 | 97.833 | 737.333 | 50.666 | 673 | 108 |
| 19 | 777 | 103.737 | 817.263 | 53.5263 | 748.5 | 114 |
| 20 | 858 | 109.65 | 901.4 | 56.4 | 8.28 | 120 |

RESULT OF DEMONSTRATION.

We may sum up the results of our discussion then, as follows:

Total weight of iron in pounds per foot $= 2\ (w_2 - 200 + w_3 + w_4 + w_0) \ldots$ I

Where $w_2$ is the weight per foot per truss of cross-girders, stringers and rails, ties, etc., to be taken at once from a table similar to Table No. 2.

We have given simple formulas for the weight per foot per truss of wind bracing $w_3$, or it may also be taken out directly from a table embodying the results of actual practice.

Finally we have for the weight per foot per truss of the truss itself, including details,

$$\text{Weight of truss} = w_4 + w_0 = \frac{(w_1 + w_2 + w_3) + L w_0}{L - 1} \quad \ldots\ldots\ldots\ldots \text{II}$$

Where the equivalent uniform load per foot per truss $w_1$, is taken directly from Table No. 1, and $w_0$ is given by Table No. 3.

$$\text{Finally, } L = \frac{3.6\,\mu d}{\alpha p^2 + \beta d^2 - \frac{\alpha p^2 + 4\,\beta d^2}{5\,(N-1)}}$$

Here $\mu$ is the numerator of the strut formula, and $\alpha$ and $\beta$ are taken directly from Table 4.

The only empiricism is in the last term in the denominator of $L$ and in the value of $w_0$. Both of these quantities are subsidiary and small with respect to the others, while the entire formula is rational in form, and has been fitted in its subsidiary empirical portions to one case only

of Mr. Pegram's examples. If such a formula thus found and fitted, checks well with practice through a wide range, it seems to me it is all I have claimed for it. The amount of calculation required is very small and requires little time when tables are used. It is simple, general and rational. The strut formula is, I think, properly introduced, and the details are taken into account. Is it accurate enough?

Accuracy of Formula.—This question can only be answered by comparison of the results with actual examples. It is sufficient to thus check II, for if this is accurate, there is no difficulty as we have seen, in knowing $w_2$ and $w_3$ directly from tables without calculation at all. The truss is the problem.

In checking II by actual examples, the actual data must be used, not those given by my tables and formulas. Those are intended for design, not for testing executed examples.

Mr. Pegram has furnished in previous discussions an extensive list of single track spans with all necessary data. He has given for each case the weight of truss $w_0 + w_4$, also the total weight of iron and weight of shoes, etc. It is therefore possible to calculate for the load systems he specifies, the value of $w_1$. He has also given $w_1 + w_2 + w_3$. We are unable to check these values of $w_1 + w_2 + w_3$ without manifest inconsistencies in the value of the rails, ties, etc., which we have taken at 200 pounds. Referring to I, we see at once, that if in any case we take half the total weight, subtract the weight of shoes, etc., which is known for each truss, and divide by the span, we have the weight per foot per truss. Subtract from this the known value of $w_4 + w_0$, and we have $w_2 - 200 + w_3$. If to this we add $w_1$ and the allowance for rails, ties, etc., we ought to have $w_1 + w_2 + w_3$.

Taking Mr. Pegram's data, I have the following tabulation:

| 1 | 2 | 3 | 4 | 5 | 6 | 7 |
|---|---|---|---|---|---|---|
| Span. | $w_2 - 200 \quad w_3$ as given by Pegram. | $w_1$ as calculated. | $w_1 + w_2 - 200 + w_3$ | $w_1 \quad w_2 + w_3$ allowing 200 for rails, etc. | $w_1 \quad w_2 + w_3$ as given by Pegram. | Allowance for rails, etc., from Pegram's data. |
| | 190 | 1 378 | 1 568 | 1 768 | 1 820 | 252 |
| 104 | 200 | 1 492 | 1 692 | 1 892 | 2 000 | 308 |
| | 207 | 1 566 | 1 773 | 1 973 | 2 020 | 247 |
| | 194 | 1 287 | 1 481 | 1 681 | 1 675 | 194 |
| 150 | 200 | 1 470 | 1 670 | 1 870 | 1 844 | 174 |
| | 215 | 1 589 | 1 804 | 2 004 | 1 950 | 146 |
| | 224 | 1 172 | 1 396 | 1 596 | 1 565 | 169 |
| 201.5 | 228 | 1 404 | 1 632 | 1 832 | 1 776 | 144 |
| | 241 | 1 542 | 1 783 | 1 983 | 1 946 | 163 |
| | 347 | 1 027 | 1 374 | 1 574 | 1 605 | 231 |
| 320 | 358 | 1 160 | 1 518 | 1 718 | 1 798 | 280 |
| | 364 | 1 515 | 1 879 | 2 079 | 2 088 | 209 |
| 255.5 | 217 | 1 526 | 1 743 | 1 943 | 1 943 | 200 |

I am unable to account for these discrepancies. The values of $w_1$ have been carefully calculated. The data attributed to Mr. Pegram are taken from his published figures, and there may perhaps be clerical errors which I cannot correct. In the last case it will be observed we agree exactly. In the third case of 320-foot span we also agree, but in the other two cases of the same span, if Mr. Pegram's values are correct and my values of $w_2$, are also correct, we have 280 and 231 for the same allowance.

As there is, I think, no error in the values of the second column, and I consider those in the third correct, I am, I think, justified in taking for the test of my formula the values of column five, instead of those given by Mr. Pegram. I am, of course, liable to correction, if I have misunderstood Mr. Pegram's data, but it is important that the value of $w_1 + w_2 + w_3$ should be accurately found if the formula is to be truly tested.

We have then the following test of the formula; taking $\mu = 8\,000$:

| Span in feet $l$ | Depth in feet $d$ | No. of panels $N$ | $w_1$ $w_2$ $w_3$ | $\alpha p_2 l \beta d^2$ | $\alpha p^2 \frac{4\beta d^2}{5(N-1)}$ | $L$ | $w_n$ | $w_1$ | Actual value $w_1$ | Per cent. of differe. co. |
|---|---|---|---|---|---|---|---|---|---|---|
| S. I. 104. | 24 | 6 | 1 768<br>1 892<br>1 974 | 43 392 | 3 268 | 14.6546 | 86 | 221<br>231<br>237 | 227 | $-2\frac{5}{100}$<br>$-1\frac{7}{100}$<br>$-1\frac{3}{100}$ |
| D. I. 150. | 25 | 9 | 1 681<br>1 870<br>2 004 | 71 641 | 2 956 | 9.6518 | 105 | 311<br>333<br>348 | 337<br>331<br>351 | $-1\frac{35}{100}$<br>$0\frac{20}{100}$<br>$-0\frac{85}{100}$ |
| D. I. 201.5 | 28 | 12 | 1 596<br>1 852<br>1 983 | 123 100 | 3 692 | 6.36 | 118 | 437<br>481<br>509 | 422<br>465<br>497 | $-3\frac{7}{110}$<br>$3\frac{16}{110}$<br>$2\frac{11}{100}$ |
| D. I. 320. | 20 | 16 | 1 574<br>1 718<br>2 079 | 287 820 | 5 918 | 3.3335 | 132 | 863<br>925<br>1 080 | 855<br>936<br>1 100 | $0\frac{93}{100}$<br>$-1\frac{17}{100}$<br>$-1\frac{81}{100}$ |
| D. I. 255.5 | 29<br>32<br>35<br>38 | 14 | 1 945<br>1 955<br>1 956<br>1 959 | 185 577<br>192 793<br>200 718<br>209 353 | 4 382<br>4 828<br>5 318<br>5 848 | 4.3966<br>4.6634<br>4.8923<br>5.0854 | 118<br>132<br>146<br>160 | 725<br>701<br>686<br>678 | 726<br>702<br>692<br>684 | $-0\frac{13}{100}$<br>$-0\frac{11}{100}$<br>$-0\frac{86}{100}$<br>$-0\frac{87}{100}$ |
| | 29<br>32<br>35<br>38 | 12 | 1 954<br>1 964<br>1 965<br>1 966 | 183 756<br>189 978<br>198 812<br>204 258 | 4 900<br>5 353<br>5 850<br>6 392 | 4.4271<br>4.7181<br>4.9251<br>5.1953 | 122<br>134<br>146<br>158 | 727<br>698<br>683<br>664 | 730<br>702<br>682<br>670 | $-0\frac{41}{100}$<br>$-0\frac{57}{100}$<br>$0\frac{14}{100}$<br>$-0\frac{89}{100}$ |
| | 29<br>32<br>35<br>38 | 10 | 1 978<br>1 976<br>1 979<br>1 981 | 182 460<br>187 730<br>193 519<br>199 826 | 5 667<br>6 137<br>6 652<br>7 213 | 4.4395<br>4.7537<br>5.0356<br>5.2859 | 121<br>131<br>141<br>151 | 731<br>692<br>666<br>648 | 715<br>686<br>661<br>642 | $-2\frac{23}{100}$<br>$0\frac{87}{100}$<br>$-0\frac{75}{100}$<br>$-0\frac{93}{100}$ |

It will, I think, be admitted that a formula put together as this one has been, employing empiric values only in two subsidiary terms, ra-

tional throughout in form, which follows step by step the main features of actual design, and which has been fitted in its empirical portion, only to the last case of the 255.5-foot span—must be correct in all important particulars, in order to give such close results over such a wide range.

In every case it gives results close enough for a bid, and it follows change of depth in the last examples with such exactness, that it is reasonable to conclude that it will give with equal exactness the result arising from any change in any of the dimensions. Any one who will refer to Table No. 4, and taking the value of $w_1 + w_2 + w_3$ as given, check any one of these cases, will be satisfied that the formula requires but little time and calculation.

Lest it may be suspected that our alteration of the values of $w_1 + w_2 + w_3$ as given by Mr. Pegram is in the interest of correspondence, we give below the results of using Mr. Pegram's own values.

| Span. | $w_1 + w_2 + w_3$ as given by Pegram. | $w_4$ by Formula. | $w_4$ Actual Value. | Per cent. of Difference. |
|---|---|---|---|---|
| 104 | 1 820 | 225 | 227 | $-0\frac{88}{100}$ |
| | 2 000 | 238 | 235 | $+1\frac{28}{100}$ |
| | 2 090 | 245 | 241 | $+1\frac{66}{100}$ |
| 150 | 1 675 | 310 | 307 | $+0\frac{97}{100}$ |
| | 1 844 | 330 | 331 | $-0\frac{60}{100}$ |
| | 1 950 | 342 | 351 | $-2\frac{56}{100}$ |
| 201.5 | 1 565 | 432 | 422 | $+2\frac{36}{100}$ |
| | 1 776 | 471 | 465 | $+1\frac{29}{100}$ |
| | 1 946 | 503 | 497 | $+1\frac{20}{100}$ |
| 320 | 1 605 | 876 | 855 | $+2\frac{56}{100}$ |
| | 1 798 | 958 | 936 | $+2\frac{35}{100}$ |
| | 2 088 | 1 083 | 1 100 | $-1\frac{55}{100}$ |

The examples of 255.5-foot span remain as before. It will be seen that the results are even better for Mr. Pegram's data than for my own. It is quite possible that Mr. Pegram's values are correct as published. But I thought it due to consistency to call attention to the discrepancies noted.

In a paper kindly sent to me some time ago by Professor Waddell is a list of carefully estimated weights of single track spans from 60 to 300 feet. The locomotive system used is very closely that which I have assumed in this paper. The values of $w_2 + w_3$ are given. We are able, therefore, at once to check our formula by Mr. Waddell's estimates. The first three spans are single intersection pony trusses, the rest down to 160 single intersection through, and the remainder double intersection through trusses. We have found, by applying our formula to a few cases, that Mr. Waddell's value of $u$ is about 6 540 for single and 5 830

for double intersection. Using these values of $\mu_1$, taking $w_1$ from Table No 1, and $w_2 + w_3$, as given by Professor Waddell, we have the following results:

| Span in feet, $l$. | | Depth in feet, $d$. | Number of panels, $N$. | $w_1 + w_2 + w_3$. | $w_0$. | $L$. | $w_1$ by formula. | $w_1$, as estimated by Prof. Waddell. | Per cent. of difference. |
|---|---|---|---|---|---|---|---|---|---|
| | 60 | 8 | 5 | 2 181 | 50 | 16.613 | 193 | 214 | — 9.81 |
| | 65 | 8 | 5 | 2 130 | 50 | 14 499 | 212 | 231 | — 8.23 |
| | 70 | 9 | 5 | 2 090 | 51 | 12 887 | 217 | 224 | — 3.13 |
| S. I. | 70 | 23 | 5 | 2 089 | 75 | 19.377 | 193 | 209 | — 7.66 |
| | 80 | 16 | 5 | 2 048 | 64 | 15.577 | 208 | 215 | — 3.26 |
| | 90 | 23 | 5 | 2 046 | 75 | 14.871 | 227 | 221 | + 2.64 |
| | 100 | 20 | 5 | 2 065 | 70 | 12.461 | 256 | 252 | + 1.56 |
| | 110 | 23 | 6 | 2 069 | 83 | 11.082 | 296 | 281 | + 5.07 |
| | 120 | 21 | 6 | 2 088 | 80 | 9.563 | 333 | 319 | + 4.39 |
| | 130 | 23 | 7 | 2 102 | 90 | 8.675 | 376 | 371 | + 1.35 |
| | 140 | 23 | 7 | 2 086 | 90 | 7.828 | 408 | 412 | — 0.97 |
| | 150 | 23 | 7 | 2 080 | 90 | 6.664 | 473 | 452 | + 4.65 |
| | 160 | 24 | 8 | 2 076 | 98 | 6.460 | 496 | 495 | + 0.20 |
| | 170 | 26 | 8 | 2 079 | 103 | 6.128 | 528 | 544 | — 2.94 |
| | 180 | 27 | 8 | 2 081 | 106 | 5.742 | 567 | 571 | — 0.70 |
| | 190 | 28 | 9 | 2 065 | 114 | 5.239 | 628 | 640 | — 1.87 |
| D. I. | 180 | 30 | 8 | 2 281 | 114 | 5 892 | 604 | 569 | + 6.15 |
| | 190 | 32 | 9 | 2 065 | 125 | 5.578 | 603 | 631 | — 4.43 |
| | 200 | 33 | 9 | 2 068 | 128 | 5.242 | 646 | 664 | — 2.71 |
| | 210 | 34 | 10 | 2 068 | 136 | 4.904 | 701 | 725 | — 3.31 |
| | 220 | 36 | 10 | 2 068 | 143 | 4.705 | 740 | 755 | — 1.99 |
| | 230 | 38 | 10 | 2 069 | 150 | 4.522 | 780 | 782 | — 0.25 |
| | 240 | 39 | 11 | 2 073 | 158 | 4.254 | 843 | 847 | — 0.47 |
| | 250 | 41 | 11 | 2 079 | 165 | 4.101 | 889 | 900 | — 1.22 |
| | 260 | 42 | 11 | 2 082 | 170 | 3.916 | 942 | 946 | — 0.42 |
| | 270 | 43 | 12 | 2 087 | 178 | 3.703 | 1 016 | 1 010 | + 0.59 |
| | 280 | 44 | 12 | 2 095 | 182 | 3.549 | 1 075 | 1 055 | + 1.86 |
| | 290 | 45 | 13 | 2 098 | 190 | 3.367 | 1 157 | 1 131 | + 2.30 |
| | 300 | 46 | 13 | 2 104 | 194 | 3.237 | 1 221 | 1 188 | + 2.77 |

As I presume Professor Waddell would not claim for his estimates absolute exactitude, the correspondence of the formula as that of estimate with estimate seems all that could be desired. The short pony spans are all greater than formula, as they should be, as there is no variation of cross-section in such cases, and hence an excess of material.

More tests are wanted, but I need hardly point out that they must be of well and uniformly designed spans, for the same or uniform specifications, and actual data must be used. For different designs and styles the value of $\mu$ may need to be changed. Thus in Professor Waddell's case we have two values, one for single and one for double intersection. But for same design and style, this value should be constant. This is equivalent to saying that if we take $\mu$ at 8 000 our co-efficient 3.6 includes really a "co-efficient of design." In the case of Mr. Pegram this co-efficient is unity. For Professor Waddell's cases it is 0.8175 and 0.72875. In any set of uniformly designed trusses it is simply necessary

to find by reversing the formula, the average value of $\mu$ and then using this average value, the formula can be trusted to reproduce the entire set and give the influence upon weight of any change in dimensions.

If no such uniform value of $\mu$ is found I think I am justified in concluding that either the spans are not uniformly designed to the same specifications or else that some of the data are incorrectly assumed.

### Mr. Hughes' Spans.

This is, I think, the case with Mr. Hughes' cases, quoted in my previous paper.

Thus one of his examples is double intersection,

$$l = 200,\ d = 28,\ N = 13,\ w_1 + w_2 + w_3 = 1\,560,\ w_4 = 474.$$

This is almost identical in every respect with one of Mr. Pegram's cases, and yet the weight as designed by Mr. Pegram is $w_4 = 422$. Taking $\mu = 8\,000$ for Mr. Pegram, we must take in this case $\mu = 7\,116$ for Mr. Hughes. But this value of $\mu$ will give only one or two of Mr. Hughes' other examples with such accuracy as we desire. The value of $\mu$ in order to give his results accurately must fluctuate considerably as is shown by the following table. The values of $w_1$ are taken from Table No. 1, and $w_2 + w_3$ as given by Mr Hughes. The last two spans are double track.

| $l$. | $d$. | $N$. | $w_1 + w_2\ w_3$ | $w_1$ actual value. | $\mu$ from formula. |
|---|---|---|---|---|---|
| S. I. 50 | $6\frac{1}{4}$ | 4 | 1 895 | 157 | 6 320 |
| " 61 | 8 | 4 | 1 810 | 139 | 8 539 |
| " 75 | 21 | 5 | 1 666 | 184 | 5 508 |
| " 84 | 21 | 6 | 1 677 | 201 | 6 714 |
| " 105 | 20 | 7 | 1 679 | 206 | 9 150 |
| " 120 | 22.5 | 8 | 1 678 | 246 | 8 960 |
| " 135 | 22.5 | 9 | 1 663 | 267 | 10 052 |
| D. I. 165 | 27 | 11 | 1 616 | 382 | 7 028 |
| " 184 | 28 | 12 | 1 573 | 414 | 7 356 |
| " 200 | 28 | 13 | 1 560 | 474 | 7 116 |
| S. I. 142 | 27 | 7 | 3 331 | 423 | 9 046 |
| " 150 | 28 | 7 | 3 268 | 409 | 10 246 |

It seems to me improbable that a rational formula which agrees so well with the results of two designers, for both of whom $\mu$ has a constant value, should suddenly prove inaccurate for a third. I must conclude as already stated, either that there is some error in the data, or that the spans have not been uniformly designed from uniform specifications, and hence to quote Mr. Pegram's remark upon these same spans, "are not sufficiently consistent to entitle them to use as a standard." Our formula, even in Mr. Hughes' case, would give good results, but not such close correspondence as we seek.

More tests of the formula under proper conditions are needed, and I trust I shall be favored with them, or with all the necessary data to enable me to make them myself.

### Least Weight Depth.

If we differentiate II and equate the first derivative to zero, we find for the depth which gives $w_4$ a minimum

$$\frac{d}{l}=\frac{1}{N}\sqrt{\frac{\alpha\left[1+\frac{1}{5(N-1)}\right]}{\beta\left[1+\frac{4}{5(N-1}\right]}+\frac{1.2\,\mu\,N}{(w_1+w_2+w_3)+A}}$$

The values of $\alpha$ and $\beta$ are to be taken from Table No. 4, and of $A$ from Table No. 3. For standard specifications and the locomotive system we have adopted, we may take $(w_1 + w_2 + w_3)$ equal to 2 000, without noticeable error.

If we use this value of $w_1+w_2+w_3$, we can make at once the following tabulation, which will enable us to find directly the least weight depth for any length of span, for Warren single or double intersection.

TABLE No. 5.

Least Weight Depth, $d = Cl$. Values of $C$, Given in Table.

| $N$. | Warren girder C. | Single intersection C. | Double intersection C. |
|---|---|---|---|
| 4 | 0.2207 | 0.2510 | 0.2592 |
| 5 | 0.1978 | 0.2258 | 0.2436 |
| 6 | 0.1805 | 0.2018 | 0.2272 |
| 7 | 0.1669 | 0.1846 | 0.2122 |
| 8 | 0.1559 | 0.1708 | 0.1992 |
| 9 | 0.1467 | 0.1596 | 0.1875 |
| 10 | 0.1389 | 0.1502 | 0.1773 |
| 11 | 0.1348 | 0.1420 | 0.1684 |
| 12 | 0.1263 | 0.1350 | 0.1605 |
| 13 | 0.1211 | 0.1290 | 0.1534 |
| 14 | 0.1164 | 0.1235 | 0.1470 |
| 15 | 0.1123 | 0.1196 | 0.1413 |
| 16 | 0.1084 | 0.1142 | 0.1360 |
| 17 | 0.1049 | 0.1102 | 0.1312 |
| 18 | 0.1016 | 0.1065 | 0.1267 |
| 19 | 0.0986 | 0.1031 | 0.1226 |
| 20 | 0 0958 | 0.0999 | 0.1187 |

If, then, our formula is accurate and follows correctly change in depth, we can easily find at once the depth for minimum weight. From Formula I and Table No. 2, and formulas for $w_3$, we can then find the weight of iron per foot for any number of panels. By a few trials we can thus find the best number of panels corresponding to the least weight depth, or, with any desired depth, can find the best number of panels.

As an illustration, take a span of 104 feet, single intersection.

For $N=4$, we have from Table No. 5, $d = 26.1$ feet. In this case $w_1 = 1\ 564$, $w_2 + w_3 = 406$, and Formula II gives us $w_4 = 207$ pounds. We have then from I total weight of iron = 826 pounds per foot.

For $N = 5$, we should find in like manner $d = 23.5$ and weight 820, and for $N = 6$, $d = 21$ and weight 840 pounds per foot.

We see at once that the best number of panels is N = 5. Local circumstances and peculiarities of design may determine the depth. In such case we can easily find for the given depth the best number of panels. In Mr. Pegram's example of 104-foot span, the depth is taken at 24 feet, or very closely what our formula gives it. But according to our formula 5 panels instead of 6 would have been better.

The formula also shows that the weight varies but little for a moderate change of depth, other things remaining the same. The least weight depth is then of minor importance except as indicating in any case the amount of deviation. The panel length is, however, of more importance, and our formula completely confirms the results towards which best modern practice has been constantly tending, viz., long panels.

The preceding will suffice to indicate the use to which such a rational formula as that which we present may be put, provided it is sound and accurate. It serves not only as a means of estimating weight but has scientific interest as a guide in design. As such uses depend entirely upon its accuracy, and as the accuracy is at present the precise point to be established, we shall not further indicate the directions in which the formula should prove valuable. They are sufficiently obvious. Until the accuracy of the formula is first established and admitted it would be a waste of time to attempt to largely apply it to problems of design.

## Empiric Formula.

As variations in depth do not largely affect the weight of truss, and the value of $w_2 + w_3$ varies but little around a constant value, it would seem possible to construct a purely empiric formula, which should contain the span as the only variable, and give at once with little calculation and with sufficient accuracy for an estimate, the entire shipping weight.

Such a formula was presented by Mr. Pegram at the annual Convention, June 10th, 1884, and published in the Transactions for February, 1886. His formula was:

$$\text{Total weight of iron in pounds} = \left(a + \frac{l}{c}\right) l \sqrt{l}$$

By giving to the constants $a$ and $c$, a series of values for the various load systems specified, and changing them when the weight deviated too much from the actual, this formula showed a good correspondence with actual weights of bridges designed according to the specifications.

We would present as equally simple and easy of application, and as more accurate so far as can be judged by correspondence, the following formulas:

$$\text{Total weight of iron in pounds} = \frac{a + b\,l}{\frac{c}{l} - 1}$$

For Mr. Pegram's "Class M," for plate girders, $a = 124\,720$; $b = 3\,415$; $c = 585$, and for truss spans under 320, $a = 301\,900$; $b = 562$, $c = 518$.

For "Class C," for plate girders, $a = 393\,880$; $b = 14\,848$; $c = 2\,040$, and for truss spans under 320, $a = 303\,000$; $b = 1\,160$; $c = 578$.

For "Class T," for plate girders, $a = 228\,612$; $b = 7\,774$; $c = 1\,110$, and for truss spans under 320, $a = 293\,343$; $b = 1\,167$; $c = 549$.

We give in the following table the comparison of the results of these formulas with the actual values as given by Mr. Pegram, also our respective percentages of error. All spans up to 80 are deck-plate girders, 8 feet wide, ties on top chord. Above 80, through Pratt trusses up to 150, and Whipple over that length.

It would seem that for the range covered, the proposed empiric formulas are considerably more accurate than those of Mr. Pegram. The constants $a$, $b$ and $c$ are easily determined for any series of executed examples, provided they are all uniformly designed in accord with uniform specifications. The values given, of course, hold good only for Mr. Pegram's cases. But any designer can easily make out the constants for his own practice. For preliminary quick estimate of weight such formulas will always possess value. I attribute the accuracy of those just given, to the fact that they are identical in form with that required by the rational discussion. Judging alone from the correspondence in the cases just given, this accuracy is sufficient for a very close estimate. While, therefore, these formulas may be used within proper limitations as giving close and ready approximations, and admit of being varied for individual practice, according to the specifications and requirements and style of bridge, the more general and rational formulas which have been given, possess, if accurate, a scientific interest and value, and take account of style and proportions.

| Span in feet. | CLASS M. Moguls and 1 820 pounds. | | | | CLASS C. Consols and 2 240 pounds. | | | | CLASS T. Typicals and 3 000 pounds. | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Actual. | Formula. | Per cent. of Difference. | Per cent. Pegram. | Actual. | Formula. | Per cent. of Difference. | Per cent. Pegram. | Actual. | Formula. | Per cent. of Difference. | Per cent. Pegram. |
| 20 | 6 841 | 6 832 | $-0\frac{13}{100}$ | $+0\frac{20}{100}$ | 6 841 | 6 840 | $-0\frac{1}{100}$ | $+0\frac{80}{100}$ | 7 047 | 7 041 | $-0\frac{85}{100}$ | $-1\frac{20}{100}$ |
| 30 | 12 523 | 12 280 | $-1\frac{14}{100}$ | $+1\frac{70}{100}$ | 12 732 | 12 541 | $-1\frac{50}{100}$ | $+1$ | 12 979 | 12 828 | $-1\frac{16}{100}$ | $+0\frac{60}{100}$ |
| 40 | 18 635 | 19 179 | $+2\frac{91}{100}$ | $+6\frac{20}{100}$ | 19 283 | 19 756 | $+2\frac{45}{100}$ | $+4$ | 19 807 | 20 133 | $+1\frac{64}{100}$ | $+3$ |
| 50 | 27 639 | 27 614 | $-0\frac{9}{100}$ | $+1\frac{40}{100}$ | 28 561 | 28 550 | $-0\frac{3}{100}$ | $+2\frac{40}{100}$ | 29 115 | 29 123 | $+0\frac{2}{100}$ | $0$ |
| 60 | 37 360 | 37 670 | $+0\frac{85}{100}$ | $-0\frac{10}{100}$ | 38 590 | 38 932 | $+0\frac{88}{100}$ | $-1\frac{20}{100}$ | 39 502 | 39 717 | $+0\frac{54}{100}$ | $-1\frac{70}{100}$ |
| 70 | 48 739 | 49 445 | $+1\frac{44}{100}$ | $-2\frac{80}{100}$ | 49 983 | 50 962 | $+1\frac{95}{100}$ | $-3\frac{10}{100}$ | 51 033 | 52 040 | $+1\frac{97}{100}$ | $-2\frac{50}{100}$ |
| 80 | 63 061 | 63 036 | $-0\frac{4}{100}$ | $-7\frac{20}{100}$ | 64 561 | 64 560 | $-0$ | $-7$ | 66 061 | 66 067 | $+0$ | $-6\frac{50}{100}$ |
| 104 | 90 555 | 90 540 | $-0\frac{1}{100}$ | $-2$ | 93 050 | 92 964 | $-0\frac{8}{100}$ | $-1\frac{20}{100}$ | 96 957 | 96 940 | $-0\frac{1}{100}$ | $-1\frac{70}{100}$ |
| 130 | 124 871 | 125 656 | $+0\frac{62}{100}$ | $+2$ | 129 688 | 131 688 | $+1\frac{54}{100}$ | $+2$ | 137 285 | 138 086 | $+0\frac{58}{100}$ | $+1\frac{10}{100}$ |
| 150 | 154 427 | 157 439 | $+1\frac{93}{100}$ | $+4$ | 163 302 | 167 192 | $+2\frac{38}{100}$ | $+3$ | 173 849 | 176 087 | $+1\frac{28}{100}$ | $+2$ |
| 175 | 204 486 | 204 209 | $-0\frac{15}{100}$ | $+1\frac{50}{100}$ | 220 006 | 219 808 | $-0\frac{10}{100}$ | $-0\frac{70}{100}$ | 232 637 | 232 834 | $+0\frac{8}{100}$ | $-0\frac{50}{100}$ |
| 201.5 | 267 410 | 264 422 | $-1\frac{13}{100}$ | $-1\frac{80}{100}$ | 286 055 | 286 584 | $+0\frac{18}{100}$ | $-3$ | 304 459 | 306 550 | $+0\frac{68}{100}$ | $-2\frac{60}{100}$ |
| 255 | 441 065 | 431 823 | $-2\frac{7}{100}$ | ..... | 468 884 | 472 985 | $+0\frac{87}{100}$ | $+4\frac{70}{100}$ | 508 415 | 512 513 | $+0\frac{80}{100}$ | $-1\frac{20}{100}$ |
| 320 | 778 552 | 778 255 | $-0\frac{3}{100}$ | ..... | 837 387 | 836 476 | $-0\frac{18}{100}$ | $+0\frac{30}{100}$ | 946 031 | 932 563 | $-1\frac{42}{100}$ | $+2\frac{60}{100}$ |

PLATE XL

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

387.

(Vol. XVIII.—June, 1888.)

# THE CONSTRUCTION OF THE POUGHKEEPSIE BRIDGE.*

By JOHN F. O'ROURKE, M. Am. Soc. C. E.

Some years ago, when the scheme of bridging the Hudson River at Anthony's Nose was a subject of frequent discussion, it was suggested by the Poughkeepsie newspapers that the physical, geographical and commercial advantages of their city made it the best point at which to locate the proposed crossing. The idea grew among the citizens, and through their efforts, the Legislature of 1871 was induced to grant a charter for its construction. In it was a clause prohibiting piers in the river.

During 1871 the promoters had surveys made and the engineering features examined. Eminent authorities were consulted as to the possibility of spanning the 2 600 feet between the shores with a suspension bridge. Among others, Captain Eads declared the span too long for practicability and recommended four piers in the river, not less than 500 feet apart in the clear. These facts were presented to the Legislature of 1872, and the charter was amended so as to permit of their construction.

In 1873, the Pennsylvania Railroad, represented by J. Edgar Thomson and A. D. Dennis, subscribed $1 100 000; the capital stock being

*The substance of this paper was presented at the Convention of 1887, but was withdrawn for revision by the author.

$2 000 000. The control passed into their hands and the immediate building of the bridge seemed assured.

The charter required that the work should be begun before January 1st, 1874, so a part of the foundation of a pier was built on Reynolds' Hill, near the site of the present east anchorage pier, and on December 17th, 1873, in the presence of a distinguished company, the corner-stone was laid with elaborate Masonic ceremonies and general rejoicing. On February 22d, 1887, this stone, with its contents untouched, was removed, and placed without ceremony or addition, in the southwest corner of the anchorage pier adjoining.

The financial world was at that time suffering depression from the panic, and money was hard to get for anything, however promising. During the following winter Mr. Thomson died, and the Pennsylvania Railroad voted that no new work should be undertaken without the consent of the stockholders. This was not to be had, so the directors could do nothing, and the project rested until 1876, when a contract was entered into with the American Bridge Company of Chicago, and the actual work of building begun.

The first river pier from the west shore was built by them to a height of 20 feet above water; the crib of the next pier sunk through 55 feet of water and 40 feet of river bed, with its top 1 foot above high water; and a third crib built, 36 courses high, but not placed, when the company suspended work in 1878.

From then, nothing was done but to keep the charter alive by extensions of time, until 1886, when a number of gentlemen, forming the Manhattan Bridge Building Company, took up the project. They acquired the rights of the American Bridge Company's assignees, and made a contract with the Union Bridge Company for the entire structure complete.

In September, 1886, operations were begun. A line, practically the same as the old one, was adopted, surveys and borings were made, and a profile obtained, from which the location of the piers was determined.

The former design was for rectangular trusses of equal lengths. The location of the second span of the new design was fixed by the existing pier; and its length of 525 feet by the 500 feet of clear span and the 25 feet of masonry required. The same length of span to the west, would place Pier 1 in the West Shore Railway tracks. A pier on the

east slope of the railway would be inadmissible. The most available site was on the bluffs west of the highway, and this was selected. By this time a cantilever design had been decided on, and the 530 feet center to center of end pins necessary to reach these bluffs was made common for all three cantilever spans. This clear span, with the half-widths of towers added, made the spans next the shores 548 feet and the center span 546 feet, which with the two connecting ones, of 525 feet, center to center of piers, located Pier 6 in the face of the rock on the east shore. The total length between anchorages was thus established at 3 093 feet 9 inches, the total length, including viaducts, 6 767 feet 3 inches.

The charter fixed the bottom of trusses at 130 feet above high water; so the height of trusses proportionate to the spans required the adoption of 212 feet above high water as the grade of base of rail. The west approach has a rise of 66 feet per mile westward out of the valley of the Hudson, and the same grade was adopted on the viaducts, since it did not further limit the size of trains.

After the adoption of the general design, the next thing was an accurate location. The West Shore road-bed is level and advantageous for base lines. Two were laid out there, each about half a mile long, intersecting the center line at a common point. The triangles had a point on center line on the east shore for a common vertex, and were nearly isosceles. The bases were measured with a common 100-foot steel ribbon with brass handles, and without a spring balance or leveling attachment. Chaining in the sunshine was avoided, so correction for temperature was exactly determined. Plugs were driven flush with the ground every hundred feet, line taken, and then, with the chain suspended, and under strong tension, a distance point was decided on after a few trials. On level ground, like the West Shore road-bed, errors of over a half inch to the mile would be carelessness.

The angles were measured with a Heller & Brightly tunnel transit. Twenty repetitions were made at each station, a reading was taken every time and the difference from the preceding obtained, to guard against errors caused by the slipping of the plates. One-twentieth of the twentieth reading gave the angle to the fraction of a second. A third triangle was measured from the south base line with a vertex on center line 82.07 feet west of that used before.

The angles of the north triangle had a deficiency of 7 seconds, those of the south triangle balanced exactly, and those of the third had an excess of 1½ seconds.

The distances as calculated were respectively 2608.66 feet, 2608.78 feet, and 2608.68 feet, average 2608.71 feet. 2608.82 feet was the distance subsequently obtained by measuring across on the ice. Some more recent triangulation of two points on the eastern shore, invisible from each other, for use in locating cribs 4 and 5, incidentally gave this distance as 2608.60 feet, although great accuracy was not intended. The triangulation to crib 3, pier 2, and upon the west bluffs, was equally satisfactory, several independent triangles differing from each other only minutely.

These triangles are all shown on the accompanying map, Plate LVI.

Work proper was begun October 8th, 1886, excavating for foundations of Pier 1; that for Pier 6, October 20th; east and west anchorages, November 10th.

Masonry of Pier 6 was begun December 6th, 1886, and finished February 17th, 1887; Pier 1, January 7th, 1887, finished March 17th; east anchorage, February 8th, finished March 23d, and west anchorage, January 26th, finished May 9th.

All shore work is first-class bridge masonry, the hearting being generally concrete. Built in each anchorage pier are four iron girders, underneath which are cross-girders, connected with eye-bars to the pedestals of the shore arms. The piers are heavier than is necessary to resist any possible effort of the cantilever spans to lift them.

The borings show the river bottom to be composed, for more than 100 feet below high water, of various combinations of mud, clay and fine sand, too soft for building upon. Underlying this pasty stuff is a very firm and hard stratum of rather coarse sand, beneath which is gravel, and about 140 feet down, solid rock extending from shore to shore.

The general design of a pier is a crib and grillage, extending from the gravel to 10 feet below high water, on this is the masonry to 30 feet above high water, upon which is a steel tower 100 feet high to pedestals of trusses. Plates XLIV, XLVI, XLVII and L.

The cribs are practically alike, so No. 5 will be described. The base is 60 x 100 feet, and the height 104 feet. It is built of 12 x 12-inch white hemlock, except the bottom course, which is of white oak. The lower part or shoe is composed of five prisms of solid timber, 20 feet high, the cross-sections of which are triangular with the bases on top, the vertices lying in the five cutting edges which divide the bottom into two rectangles each, 30 x 100. The top surface of this shoe is 10

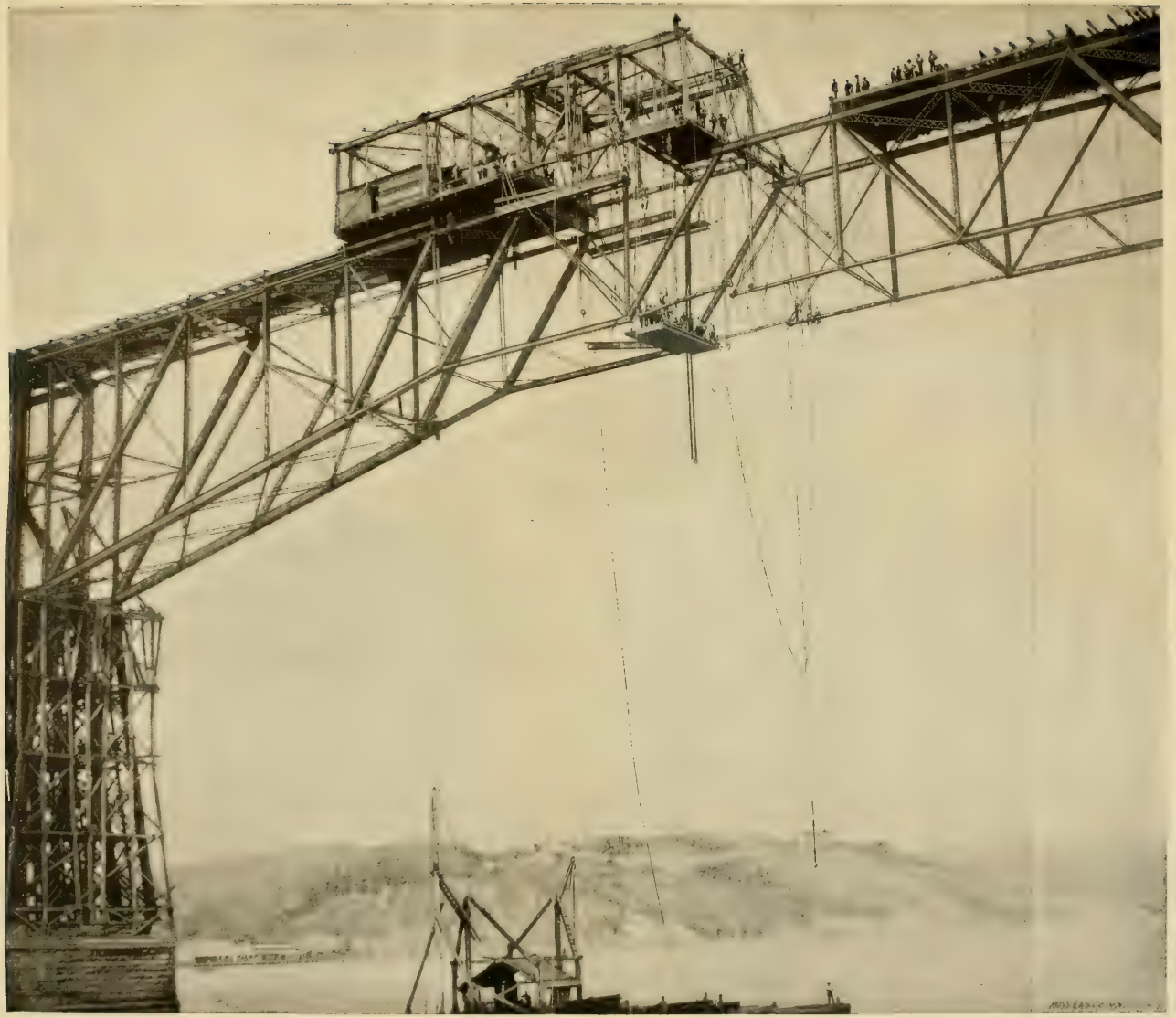


PLATE XLI.

feet wide at the sides, 9 feet at the ends and 16 feet in the middle. These prisms inclose two truncated pyramidal spaces, the tops of which are 12 x 82 feet. These spaces are divided into fourteen smaller ones, by six bulkheads of timber, 2 feet thick, that are built into the solid cribbing from the cutting edges up. These subdivisions are called the dredging chambers, and are 10 x 12 feet on top. Upon the shoe rest the weighting pockets. The walls of these are of 12 x 12 timber, 2 feet thick, and built along on the edges of the top surface of the shoe, and on the bulkheads of the dredging chambers. They, in every instance, intersect each other and extend from out to out of the crib. The building is done without halving, by laying all the longitudinal timbers of one course across the intersections, the transverse ones being cut the length of the spaces between. The next course is laid with the transverse timbers running across the intersection, while the others are fillers.

The drift bolts used are 1 inch round by 30 inches long, 450 to each course. The number was determined by learning from experiment that a 1-inch bolt driven into a $\frac{15}{16}$ hole adhered about 422 pounds per linear inch. It was assumed that the buoyancy of all the parts above the solid cribbing could act at once on all the bolts through that joint. The number of bolts giving a safe excess of resistance was made uniform for all the courses.

The openings over the dredging chambers are the passages through which the dredge bucket descends. They are called the dredging pockets.

Cribs may be built for some height on ways and launched, or they may be built on the ice about three courses high and cut in. Building is continued alongside a wharf until the draft is nearly the depth of the river, when it is taken to the pier site, anchored, set, the weighting pockets loaded with gravel to keep the top at a convenient distance above the water, and built upon until it is embedded in the mud. Weighting, building and dredging are then carried on with more or less continuity until the crib has reached its final resting place.

The borings give an approximate idea of how far a crib should go to reach a reliable bottom, sufficiently close for general plans, but the dredge bucket is better, and a close attention to its working and contents gives a true idea of the character of the strata.

Twenty feet below high water was adopted as the depth to which the

top of the crib was to be sunk, so it follows that it must be finished off, while it has yet about twenty feet to go. When dredging begins there is no side friction. The material is soft, and the crib follows the dredging easily and evenly. When the crib has penetrated perhaps 20 feet into the bottom, the material is more compact and side friction has become considerable. It no longer moves steadily, but by intermittent, though gradual descents. Toward the end the crib hangs until the bottom is undermined, when it drops sometimes as much as 10 feet at once, its motion being like that of a weight set free on the surface of a thick, soft cushion; and it comes to rest without jar. The dredge can only dig well holes, whose areas are about one-fourth that of the bottom of the crib, and it must depend upon the material falling in from the sides for the greater part of the excavation. These holes are often 30 feet below the cutting edge when in hard material, which is not sand, so a timely knowledge is obtained of how far down the crib should go, and to what height it should be built. The top course timbers floor over the entire surface, except the dredging pockets, after the weighting pockets have been filled flush with the course below. Upright timbers, about thirty feet long, are then fastened to the inner sides of alternate pockets to indicate to the dredge runner their position when under water, and clusters of piles are driven around the crib for the dredge to lie against when the former is below the surface of the water. Toward the end the dredging must be done with great care, and only a few bucketfuls removed from each pocket as the dredge goes round and round the crib. It was found that when out of level in hard material a crib righted itself if the material was left highest on the high side, as the momentum in falling is greatest there. In soft material, the crib settling slowly along with the dredging, that keeping the bottom low under the high part, remedied the difficulty. When the crib has made its final descent all the loose material is dredged out, and filling the dredging chambers and pockets with concrete is begun.

The concrete is lowered into place in boxes carrying a cubic yard; a tag line attached to a trip unlatches them at the proper time, and it is deposited without being scoured. These boxes are hung over the ends of scows, from which project the mixers. The latter are simply rectangular boxes of plate iron, provided near each end with cast-iron collars, each grooved to retain itself on a couple of wheels, and are turned by means of a small engine which forms part of the machine. A jet of

water inside and a curved pipe to the level of the mixing deck for feeding, completes an effective machine. The mixer is set at an inclination of about 4 degrees, so that the concrete may pass along as it is rapidly turned over and over. On the deck of the scow gravel is mixed dry with 1½ barrels per cubic yard of cement, whence it is wheeled in barrows or cast into the feed pipe. By this method 400 cubic yards are placed by two outfits in ten hours. The accompanying drawing, Plate XLVII, shows the operation at Crib 3. When the crib is filled with concrete to within 2 feet of the top of pockets, the remaining part is filled with broken stone and leveled by divers.

The floating caisson is then towed to place over the crib, fastened with four anchors, and the masonry begun. When the caisson is just afloat at high water only, it is accurately set, and masonry and loose stone enough to hold it down put in before the next high tide. Then an exact location of the pier is made, using a suspended piano wire to lay out the span. From this point on the work is ordinary building until the masonry is completed and ready for the steel tower. The ashlar is in courses varying in thickness from 2 feet 9 inches to 1 foot 10 inches. The use of concrete backing, with large stones imbedded in it, enables about 125 cubic yards per day to be laid, and gives a pier which is practically a monolith.

Domestic cement is used in the concrete for the cribs, Portland cement in the masonry. The mortar is mixed of one part cement and two parts sand, and the concrete backing contains 1½ barrels per cubic yard. All cement is rigidly tested in the manner recommended by the American Society of Civil Engineers. Ten per cent. of the barrels are sampled.

The testing machine used was designed by the writer for this work. Its capacity, which can be readily increased, is 1 000 pounds, and it is simple, compact and reliable. From the drawing attached, Plate XLIII, it can be easily duplicated by an ordinary mechanic.

It is worthy of note that the best results were obtained when the opening between the jaws of the clips had been increased to 1¼ inches. With a smaller opening the briquettes broke where held, instead of at the smallest section. Even with the enlarged opening the older briquettes often break at the clips.

Pier 2, as before stated, was built to 20 feet above high water by the American Bridge Company. It was 22 by 68 feet, and was to have been

carried to top of bridge. The steel towers designed by the Union Bridge Company require piers 25 by 87 feet, and consequently the old masonry was too small. (See Plate XLVIII.)

The crib of this pier is like the one described, differing only in that it is 10 feet narrower, that all the pockets are filled with concrete, and that it has iron cutting edges. It was begun in August, 1876, and launched in March, 1877.

During that season it was brought to place and completed. Its upper eight courses were calked, and a coffer-dam was built upon it. This was begun while the top was yet out of the water, and continued as the crib settled.

When in place, the cutting edges were 100 feet below high water, and the top 30 feet below same. After the dredging chambers and pockets were filled with concrete, the coffer-dam was pumped out. The upward pressure of a 38-foot head proved greater than the united resistance of drift bolts, concrete and weight of everything above bottom line of calking. The whole mass above that line lifted at the north end, hinging at the south end. As the water entered it settled back, but the bolts and débris prevented its closing, and left a space of about 8 inches at the north, which runs out to nothing before reaching the south.

A bearing below this rupture was obtained by sinking a pneumatic caisson 8 feet through the crib. It is 16 feet high, and the top is 22 feet below high water. Upon this rests the masonry.

To remove this masonry from the top of the caisson, or to in some way avoid doing so, and yet construct a good homogeneous base for the larger pier, was the problem.

The crib is 50 by 100 feet, the pneumatic caisson 29 by 74 feet and 8 feet higher, so it was decided to sink a coffer-dam 43 by 96 feet 6 inches down on the top of the crib, fill up the inside with concrete to a point a little below that from which it would be necessary to remove the stone, pump out the coffer-dam, take down the old masonry, tie together securely the coffer-dam, concrete and old pier, and cover the whole with more concrete, upon which the new masonry was to rest.

The building of this coffer-dam was begun January 20th, 1887. It is substantially two thicknesses of 12 x 12 timbers laid horizontally and separated by vertical timbers of the same size. The horizontal timbers were fastened through each post with ¾-inch round by 36-inch screw-bolts, the ends being held down by ¾-inch square by 24-inch drifts.

PLATE XLII
TRANS. AM SOC CIV ENGNS
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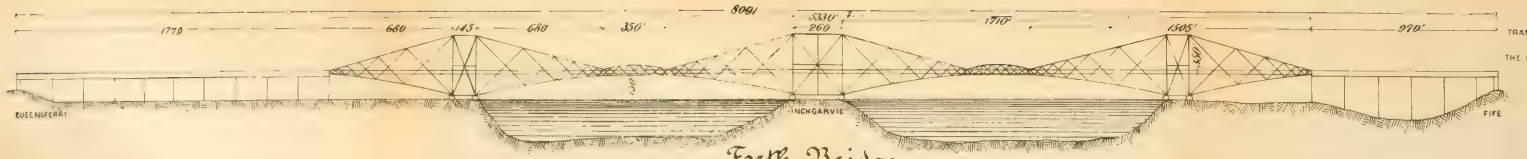
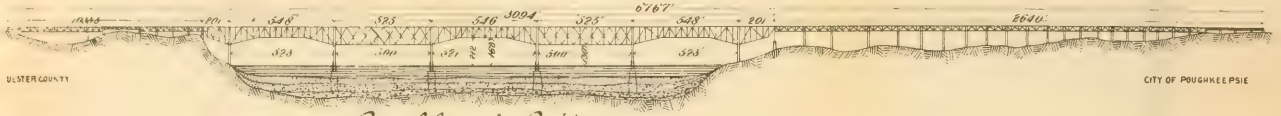
O ROURKE ON
THE POUGHKEEPSIE BRIDGE




Forth Bridge.




Poughkeepsie Bridge.

New York and Brooklyn Bridge.

Illinois and St. Louis Bridge.

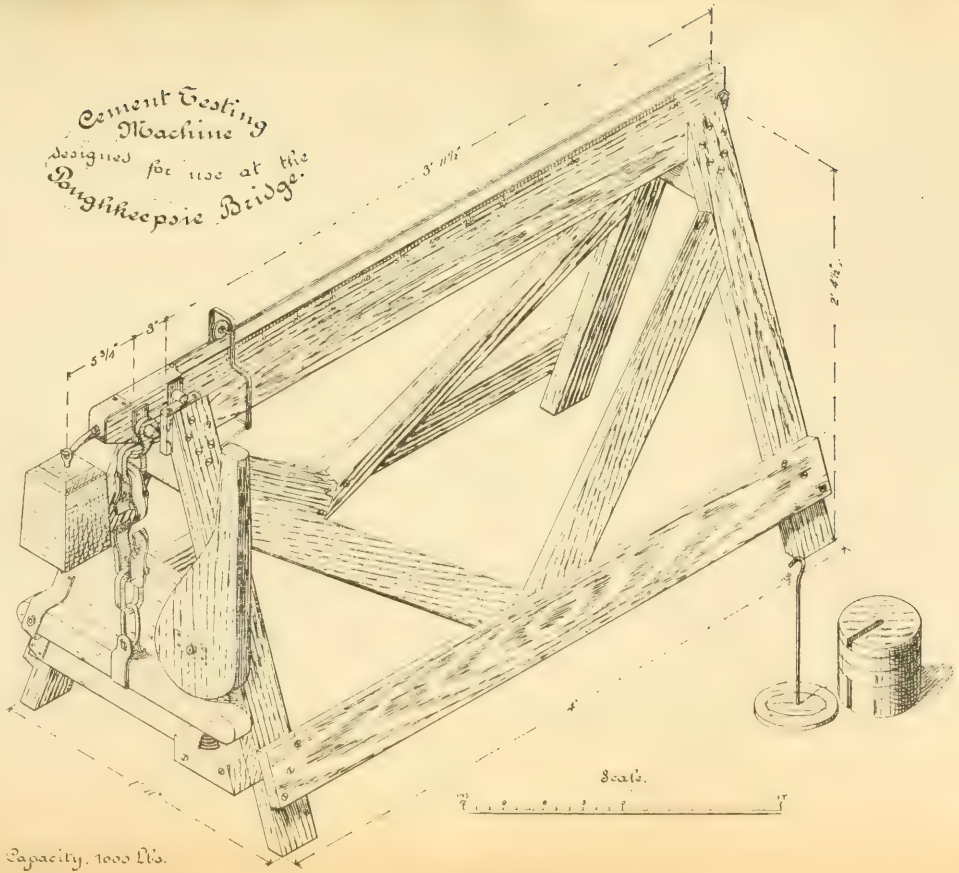
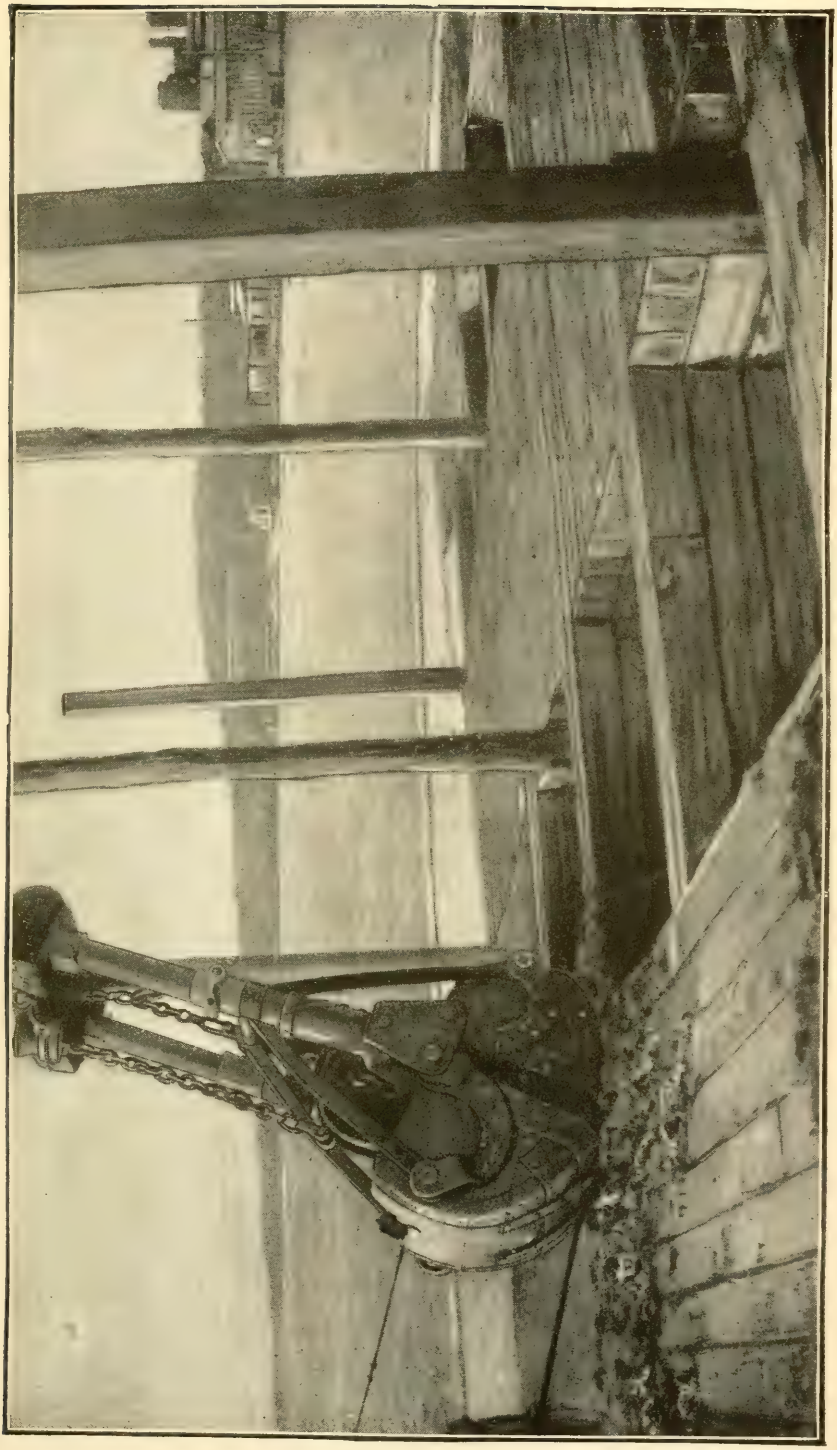

Cement Testing Machine
designed for use at the
Poughkeepsie Bridge.
Scale.
Capacity. 1000 lbs.

PLATE XLIII.

The bottom course had 12 x 12 fillers, making it solid, so that the spaces between the posts were pockets. These were filled 16 feet high with concrete, and the remainder with clay.

Building it was begun on the ice, and after three courses were laid it was cut in. About one-third of it floated above the water, and every course was calked on the outside before immersion. When some twelve courses were laid, concreting the pockets was begun and carried on at a rate to keep the top conveniently high above the water. This concrete was lowered in boxes 10 x 16 x 36 inches, and discharged through the bottom by means of a latch and tag line. When the filling changed from concrete to clay, the latter was shoveled in and rammed as well as could be done. It may be said here that it was a mistake to use clay, for it could not be rammed solid, and was constantly escaping and giving trouble. The coffer-dam was finished March 1st, 1887. In a few days it was brought to a good bearing on the crib, and all the inequalities under it were leveled by the divers with concrete in bags. Some of the concreting inside the dam was done while the ice would bear, after which, until the latter went out, work was suspended. When the river was again clear, concreting was resumed and carried up to 12 feet below high water Then the dam was pumped out and the old masonry removed to 9.5 feet below the same. Across the top of this were laid 1½ x 2-inch iron bars; attached to each pair were semicircles 5 feet in diameter of the same size iron, having ½ x 8-inch plates riveted on their inside. These hung over the masonry to a foot or two below, and were attached to the coffer-dam with stirrups of 2 x ¾-inch iron. The bolts of the dam have the nuts inside, so the ends of the stirrups simply took the place of the washers. Four similar bars run lengthwise through the pier, and are fitted to the ends of the dam in the same way. Everything was then wedged to a bearing, the water was admitted, and the whole covered with concrete to a foot above the old masonry. After a few days had been given the concrete to harden, the dam was again pumped out, and the new masonry begun. All the concrete used was composed of two parts of Alsen's Portland cement, three parts sand and six parts screened gravel. It was all deposited in water, and samples brought up by the divers as the work progressed, showed it to be as good as if it had been deposited in air.

The crib of Pier 3, as before stated, was 96 feet high, and the cutting edge down to 95 feet below high water when the Union Bridge Company



took the work. Some rotten timbers in the three top courses were replaced by sound ones, and four feet of solid cribbing was added, to bring it to a height of 100 feet, after which the dredging was begun. This went very slowly at first, and the crib did not settle until sand was reached, the buckets making only wells down through the clay. The sand, however, flowed into the holes, and the clay being undermined, the crib settled six feet at one end and four feet at the other. This was four weeks after dredging began. For the next two weeks it went down with comparative uniformity, when it again hung, the cutting edge being at elevation 118 feet. This is the level of hard sand, and as it was desired to get it into the latter a few feet, the dredging was continued. On May 21st it dropped between 7 and 8 feet, canting, at the same time, a couple of feet to the west. It had been leaning in that direction from the first, and the result of this last move was to make the center of crib 5 feet east of center of span, 1 foot higher on the east than on the west, and 1 foot higher on the north than on the south. The crib being 60 feet wide and masonry 25 feet, there is yet 12½ feet of crib outside the masonry on the east. As the resultant of pressures and center of bottom of crib practically agree, we felt no doubt of its perfect stability, yet for convenience in construction a week or more was spent dredging to the rock, and outside, on the east, to bring it level, but the crib remained immovable. The masonry is laid on a bed of Portland cement concrete, the top of which is level when the caisson rests on the crib.

Crib 4 had been moored nine years at the Whale Dock, Poughkeepsie. It was towed from there on Thanksgiving Day, 1886, to the south end of Crib 3. Five feet of rotten timber were removed, and then building upon it was begun with the thirty-second course and continued to the fifty-sixth, when it was ready for anchoring in place. This is a difficult operation under the most favorable circumstances, with the dead load of more than 5 000 tons. It is an unwieldy bulk, having a large vertical outside area submerged, and several thousand square feet additional of walls inside against which the current from underneath would act. It was drawing 52 feet of water.

The first preparation was to place anchors in the river and to leave the ends of the cable accessible. These anchors, as shown by the drawing, Plate LVII, are simply cribs, measuring on the inside 6 x 6 x 6 feet, and contain 8 cubic yards of broken stone. They are composed of 3 x 8-inch hemlock planks, 10 feet long, piled on each other so as to leave

the above inside dimensions. Through the corners are eyebolts of 1¼-inch round iron, which serve the double purpose of binding the whole together and carrying the rope slings to which the cables are attached. There are also light screw-bolts through the middle of the sides to carry a cross-piece for reinforcing the bottom. When ready for filling these cribs are placed on greased ways on a scow, in the manner shown, usually one on each corner, and fastened with rope to the deck. They are filled with stone, the tops are put in, and, if not done before, slings of 7-inch rope are spliced through each pair of eyes and wrapped with sail cloth where liable to chafe. The slings are then gathered in iron thimbles, round which the cables are bent, and fastened with three clips each. They are then ready for launching.

The mode of placing is to tow the scow out to a range line marked on the nearest shore and shift about on that until signaled by a transit-man, when the rope attaching the anchor to the deck is cut, allowing it to slide overboard. The cable is slowly paid out until the end is brought to the pier site and buoyed, or made fast to a scow, in either case marked with a tag.

In the beginning three up-stream and three down-stream anchors, with two lighter ones for each side, were thought sufficient. At the first attempt to set Crib 4 there was delay in unmooring, and the spring freshet just setting in made the ebb tide early, so it had commenced running when we got away. Before proceeding far it grew too strong for the steamer, and the latter dropped back to Crib 3. Preparations were made to draw the crib up again where it had been. Two more steamers were attached, a cable to Crib 3 was put on a capstan and a line was connected to the cable of one of the anchors. The tide grew too strong, however, the new 9-inch towing hawser attached to the largest steamer broke, then the capstan was dismantled as the crib commenced to drift, and soon it was going down the river dragging three steamboats and one anchor with perfect ease. The crib was drawing within a few feet of the depth of the river in the deepest place and grounded once or twice, but the tendency in such cases is to follow the trend of the stream. It had gone three miles when the tide turned, after which it was brought back at midnight to Crib 3 without accident. This was, perhaps, the most difficult feat accomplished in connection with the work. A full and very bright moon, and an entire absence of wind alone rendered it possible.

This experience and the fact that the freshet was hourly growing stronger gave a different idea of the force to be contended with. The number of up-stream and of down-stream anchors was increased to five, the ends of the cables were this time placed on a scow at the pier site, and on the afternoon of April 11th the crib was again towed out. The five up-stream anchors were fastened on before the tide grew strong, but when it did, the crib commenced dragging them slowly. Then surging set in, and soon the northeast cable parted, after that the northwest one, and then it dragged the other three anchors very readily. There was just time to fasten the five down-stream anchors when the crib brought up on them and was held. So it stood for three days, until the same number of anchors was again ready. Two of the up-stream anchors were behind clusters of piles. This time the crib was securely moored in place after several hours' hard work. There was some motion when the cables were drawn up tense. It was expected to stop this by grounding, but the bottom scoured as fast as the crib settled. On the 19th it commenced surging badly and dragging the anchors, and on the morning of the 20th parted the cables of the anchors behind the piles, dragging the others 300 feet down stream. On the next ebb tide several more cables were parted, the crib commenced to drift slowly down stream, and it seemed as if it would get away. The freshet at this time was so great that the tide did not run up stream in rising, and when the ebb was at its strongest, seemed to run in surges, one moment lacking off from the cribs smooth and gentle, and the next breaking at one or both corners in angry potholes. The crib surged and dragged and plunged with exceeding force, and it seemed as if nothing could hold it. New anchors were being constantly attached, scow loads of which were following it up. In launching them allowance had to be made for the distance the crib would drift while the ends of the cables were being brought aboard and fastened, so that they would just reach and give the most favorable lead. Soon there were ten on which held. Two steamers kept the crib from turning around, and so things stood until the 22d. At this time half the anchors were parted, and she had to be brought up before the preparations were entirely complete, or else go out with the next tide. The crib was now drawing 56 feet, and on the way back to place had to crush several of the lost anchors. We were now very expert in handling cables, and soon had six anchors on her bow, as the up-stream end might be called. A cluster of piles was in front of each up-stream

anchor. There were also five side anchors, two cables attached to Crib 3, and three anchors down-stream, when we left late that night, but in spite of all, the crib surged badly and two steamboats were kept pulling to steady it. The next morning two additional bow anchors and four more side anchors were put in. When they were all tightened up to perhaps 10 tons' tension each, the crib was immovable. Then it was felt that she had made her last trip. Two days more were occupied in setting her in position, clamping the cables permanently on horns outside, equalizing the tension, and removing the tackle.

It may be asked why we so underrated the forces to be controlled. At first, there was nothing to guide us but the experience of the builders of the first two cribs, and we used precisely what succeeded with them. Modifications were made as the necessity seemed to grow, and success was finally achieved when the working strength of the cables was nearly 1 000 tons. Their aggregate length was about three miles. Such a freshet in the Hudson is unexampled, and the work was done when it was at its worst.

The current, as measured, was about 2½ miles per hour, on an average, but there were times when it seemed more than twice that. There is no way of obtaining the exact pressure due to this cause under the circumstances, but one of the effects observed may give a good approximation to the stresses in the cables. When the tide was strongest, the end of the crib opposed sank two feet deeper than in still water, the other end rising about 6 inches. This is probably due to the vertical components of the stresses in the up-stream cables. The displacement was 2 000 cubic feet, or about 60 tons, of which, perhaps, 40 tons go to that end. Length of cable is to depth of water as eight to one, which would give, approximately, 320 tons as total stress in cables at north end, of which, perhaps, 240 tons went to the eight up-stream cables, the remainder to those side ones which were a little up-stream. So it would appear the cables were worked up to their limit, which was shown also by the strands drawing in places.

The anchors of Pier 5 were placed eight up-stream, six down-stream, and eight at the sides, as shown by drawing, Plate LVIII. The use of piles in front of them was abandoned, since the anchors never drew up to the clusters, except when the crib dragged from surging. They were placed in groups, so as to draw in nearly the same line. For putting the cables under tension, an engine having six spools was used with great success,

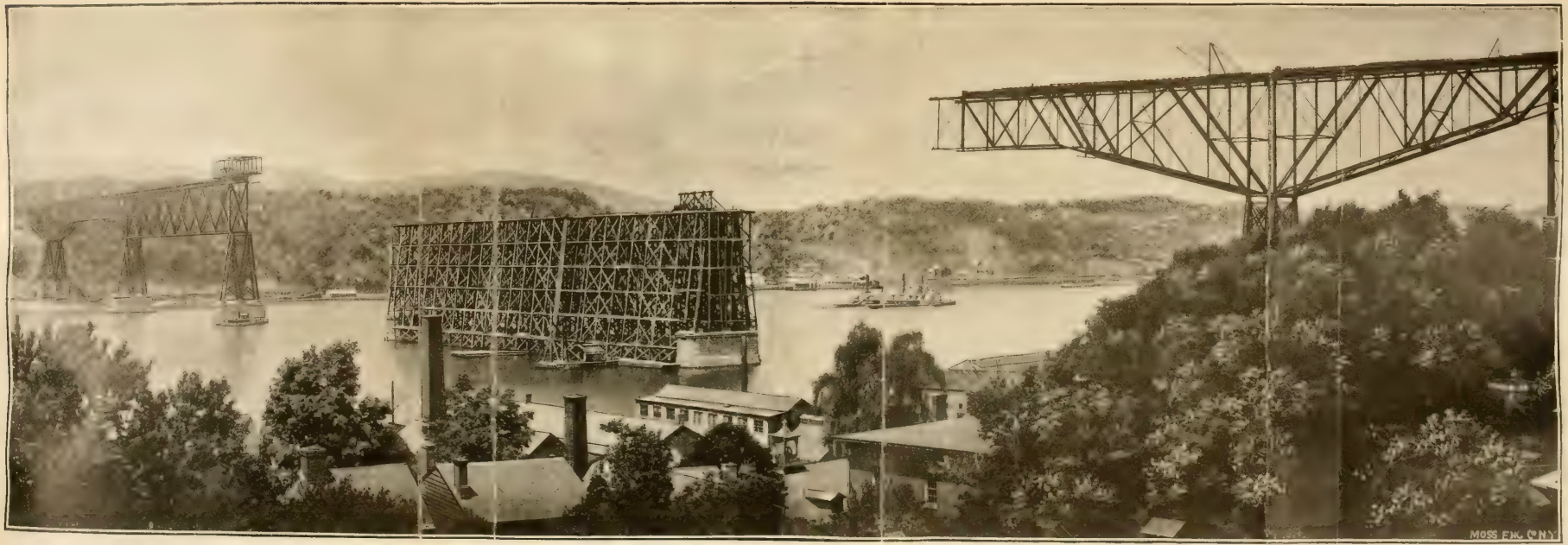



PLATE XLV

as several could be tightened at one time, more equally, and to a greater strain than with men. This crib was towed out and made fast on the afternoon of May 25th. On that of the 26th it was placed exactly in position. No trouble was encountered at any time. The tide was not so bad as when Crib 4 was set, but the ebb was yet abnormally strong. The anchors were those used on Crib 4. They were lifted with a pile-driver, towed to their new positions and deposited without mishap. Notwithstanding the rough usage they had undergone, only one of those raised was found to be broken.

The dredging proceeded very evenly on Cribs 4 and 5. The daily progress of each, including building, loading and dredging, was about one foot per day. It is possible, by building during the day, and dredging and weighting by night, to double the speed.

This method of sinking foundations is applicable wherever mud, clay, or sand, has to be penetrated. While the bottom remains unsafe for founding on, it can be dredged, so there is practically no limit to the depth that may be attained.

It is not intended, in this paper, to treat of the design or manufacture of the superstructure, but some notes regarding the erection may be interesting. There are four sets of false-work for the main bridge, two sets for the shore arms, and two for the connecting spans. The former extend to the bottom of the upper chord. Their noteworthy features are great height, and the permanent character of the framing and bolting necessary to secure stability.

For the connecting spans, the depth of the water and the character of the river bed necessitate the use of compound piles 130 feet long. There are 22 bents of 24 piles each. They are made of two yellow-pine piles, with the butts dressed for a distance of 10 feet to an octagonal cross-section of 12 inches' diameter. These are spliced with eight pieces of spruce 4 x 5 inches x 20 feet long, fastened flatwise with $\frac{7}{16}$-inch boat spikes, 8 inches long, driven 1 foot apart. It occasionally becomes necessary to draw some of these piles. The bond is broken by additional driving. The first few blows upon the pile, with a 6 500-pound hammer and a fall of 4 feet, hardly move it, although when driven it went a foot with the final blow. When started in this way, it would hold together to be drawn out; and could then be suspended horizontally from the middle without showing less stiffness at the splice than elsewhere.

There are 528 piles for a span, arranged in sets of three under each post, firmly braced above low water, and fastened to the masonry at each end. The load on each pile will be about 5 tons, which the hammer test mentioned shows to be much less than its carrying capacity.

The caps of piling are 12 feet above high-water, and from them the trestle work extends to the bottom chord, an elevation of 130 feet. Details of this trestle are shown by accompanying drawings.

The deck of the false-work is occupied by four tracks. The two outer tracks are of 8-foot gauge, and upon these runs the large traveler for the erection of the span, which extends entirely across the space between these two outer tracks. The two rails next inside of these outer tracks are occupied by a hydraulic riveting apparatus, which spans the space, 19 feet wide, between these two rails. A single track of 4 feet, 8½-inch gauge at the center of the false-work, carries the cars conveying the material.

The traveler is composed of four bents, 95 feet high, 56 feet wide at the bottom, 62 feet at the top, and set 22 feet apart between centers. It encloses an opening 38 x 82 feet 6 inches, inside which the trusses are erected.

Some of the pieces to be handled weigh more than 20 tons each, so the derricks and rigging of the false-work and travelers must be proportionately strong. Two falls, of 16-inch triple-blocks, and 1¼-inch rope, are used in raising the very heavy pieces. Some of the engines have six spools, and handle independently that number of lines.

The hydraulic riveter is carried on a small traveler, so spanning the two middle tracks as not to interfere with the transportation of materials on them. It consists of a boiler, engine and pump, by which power is supplied to the accumulator in the form of water supporting a heavy weight. The jaws are hung with differential pulleys from a worm gear set upon projecting timbers of the deck, which revolves like a turn-table. By this means the jaws are readily adjusted to any rivet in the bottom chord.

The towers at the ends of the span are first erected. Next, commencing at the fixed end, the bottom chord is laid along in place on camber blocks. The traveler then erects the span, commencing at the middle, and finishing each half successively.

From the shore arms and connecting spans 160-foot cantilevers are erected by means of projecting travelers, almost identical with those

Crib, Grillage and River Pier, Poughkeepsie Bridge. —

PLATE XLVI
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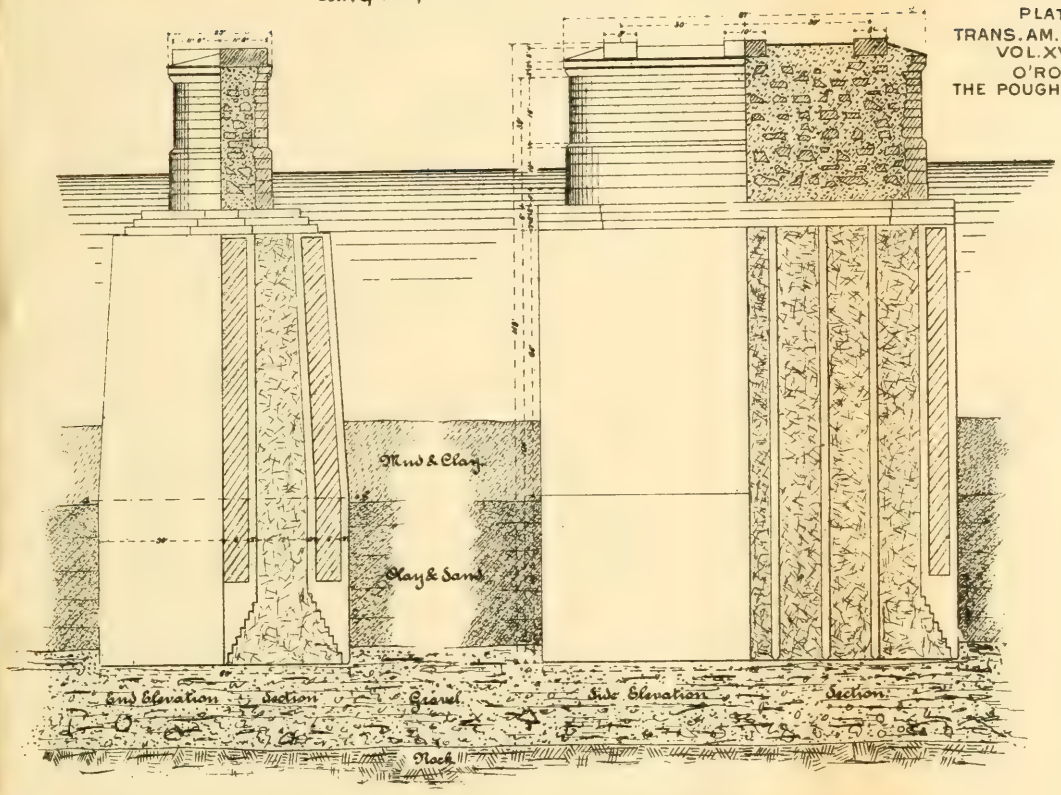
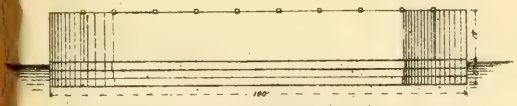
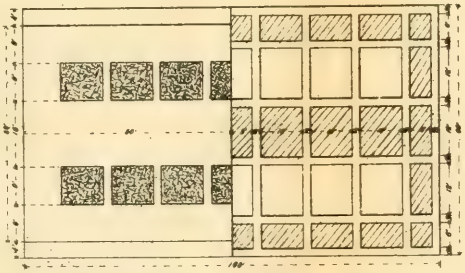
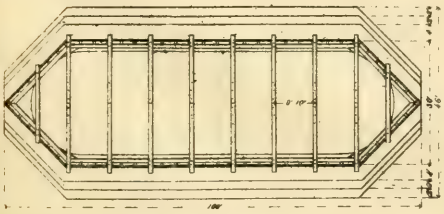


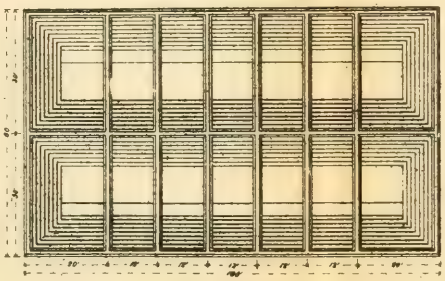
Side Elevation, Floating Caisson.



Plan of Top. Section on a b.



Plan, Floating Caisson.



Plan of Bottom.

used for erecting the cantilever bridge across the Niagara River. They are composed of two trusses, 118 feet long, of which the chords and vertical posts are of wood, and the ties and splice-plates of iron. These are supported on a very heavy floor, extending from the rear end to within 50 feet of the other end, and are carried on twelve wheels, arranged in groups of one, two and three, respectively. Jack-screws, bearing on the front floor beam, relieve the wheels during the erection of a panel, and heavy hooks, under strong tension, clamp each end to the floor beams.

The 212-foot spans suspended from the ends of the cantilever arms are designed to be erected from the ends of the latter, and connected when they meet at the center. Stiff bottom chord, except in the middle three panels, enables each panel, when finished, to support the traveler during the erection of the next beyond. When the travelers meet, the remaining three panels are completed. In connecting the center panel, the top opening should be a little long in order to let the chord section into place, and the bottom one a little short, that the pins may drive easily into the eye-bars. This is insured by adjustment struts between the arms and suspended span, which are shortened in the top chords, and lengthened in the bottom by rollers separated with wedges. They are so arranged, that by drawing them the ends of the top chord approach each other, and those of the bottom chord recede. After the span is connected, the wedges and rollers are removed, and the trusses hang suspended.

The illustrations accompanying this paper are as follows:

| | | | |
|---|---|---|---|
| Plate | XL, | Page 199. | Photograph of the Finished Structure. |
| " | XLI, | " 202. | The Cantilever Span in Progress of Erection. |
| " | XLII, | " 206. | Comparative Views of the Forth, the Brooklyn, the St. Louis and the Poughkeepsie Bridges. |
| " | XLIII, | " 207. | Cement Testing Machine. |
| " | XLIV, | " 208. | Photograph of Crib. |
| " | XLV, | " 212. | Photograph of the Structure in Progress. |
| " | XLVI, | " 214. | Crib, Grillage, River Pier and Floating Caisson. |
| " | XLVII, | " 216. | Concreting Crib 3. |
| " | XLVIII, | " 216. | Pier 2. |
| " | XLIX, | " 216. | Shore Arm Falsework. |
| " | L, | " 216. | Main Falsework with Traveller. Section of Finished Structure. Method of Splicing Piles. |
| " | LI, | " 216. | Traveller for Erection of Truss Spans. |
| " | LII, | " 216. | Traveller for Erection of Cantilever Arms. |
| " | LIII, | " 216. | Twenty-Ton Derrick. |
| " | LIV, | " 216. | Cross Section of Viaduct. |
| " | LV, | " 216. | General Plan of Floor System. |
| " | LVI, | " 216. | Triangulation and Topography. |
| " | LVII, | " 216. | Anchors. Method of Launching Anchors. Crib Anchored in Position. |
| " | LVIII, | " 216. | Method of Anchoring Cribs. |
| " | LIX, | " 216. | General Profile of Bridge. |

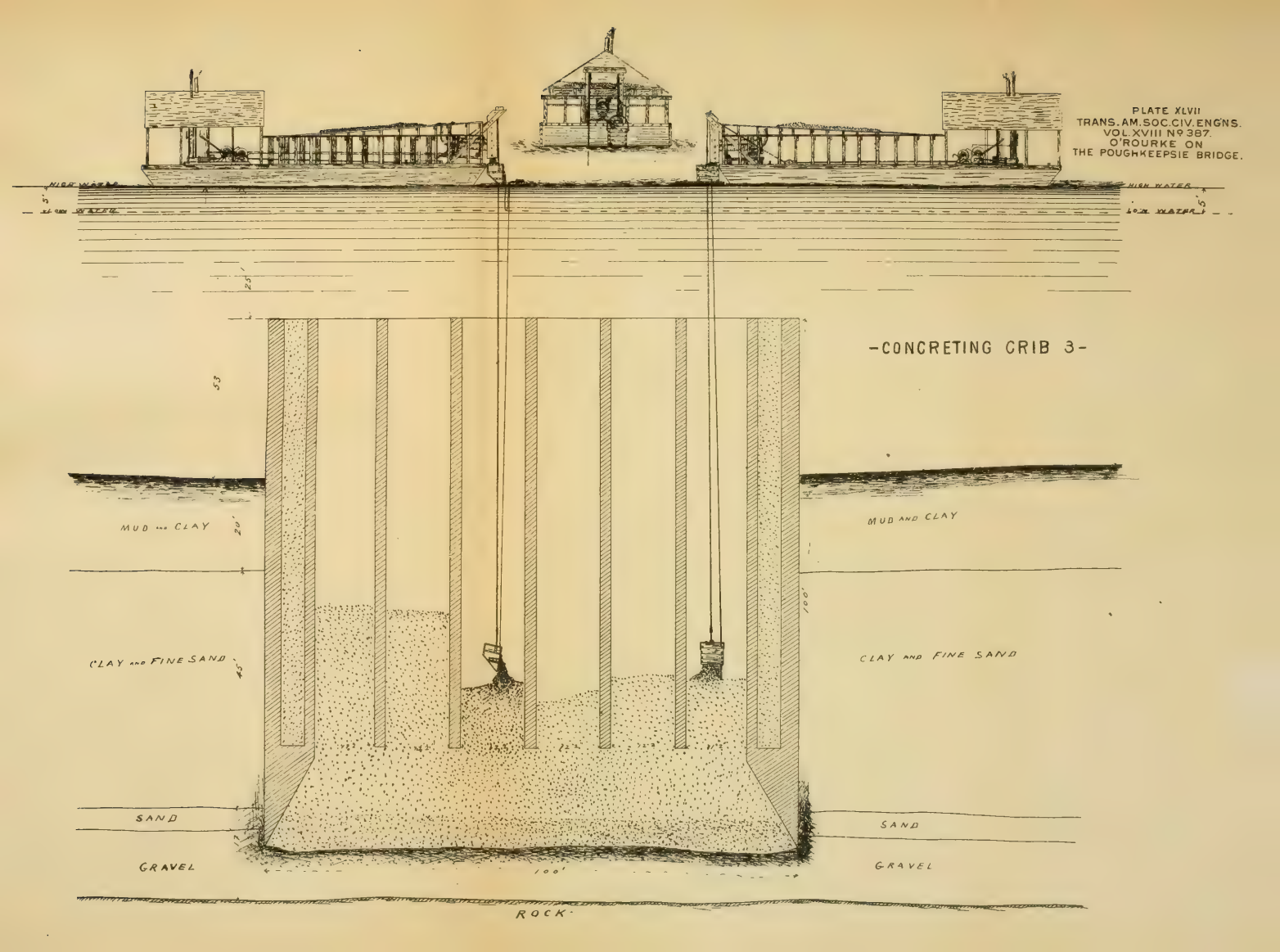


PLATE XLVII
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-CONCRETING CRIB 3-
HIGH WATER
LOW WATER
MUD AND CLAY
CLAY AND FINE SAND
SAND
GRAVEL
ROCK
100'

PLATE XLVIII
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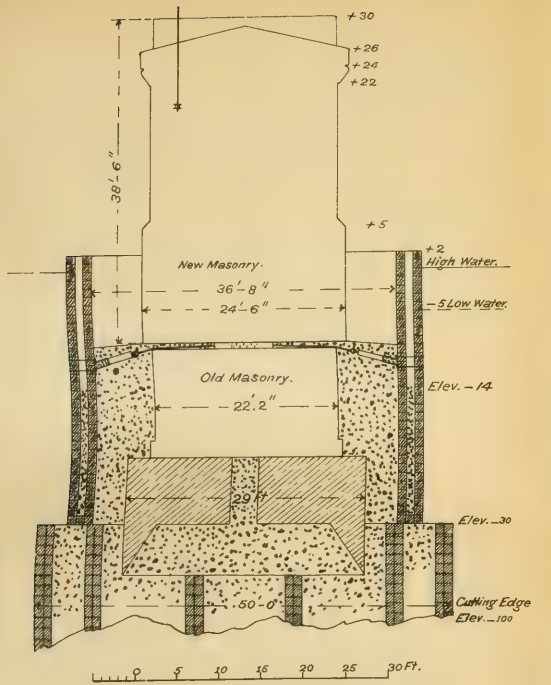
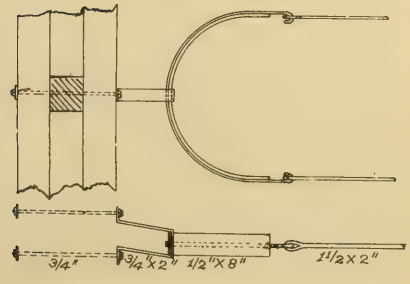
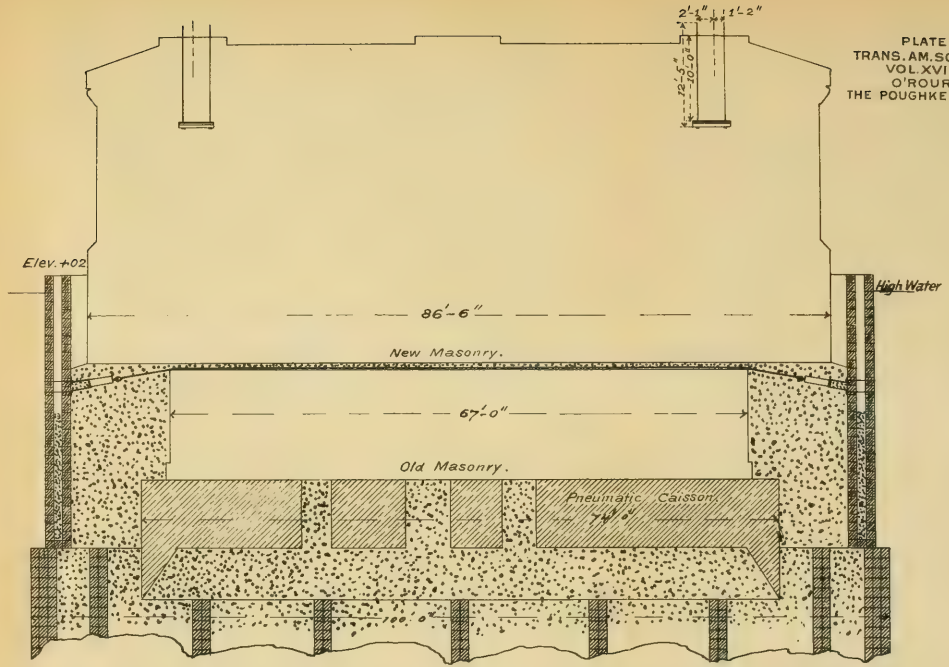
THE POUGHKEEPSIE BRIDGE.




PIER 2 POUGHKEEPSIE BRIDGE



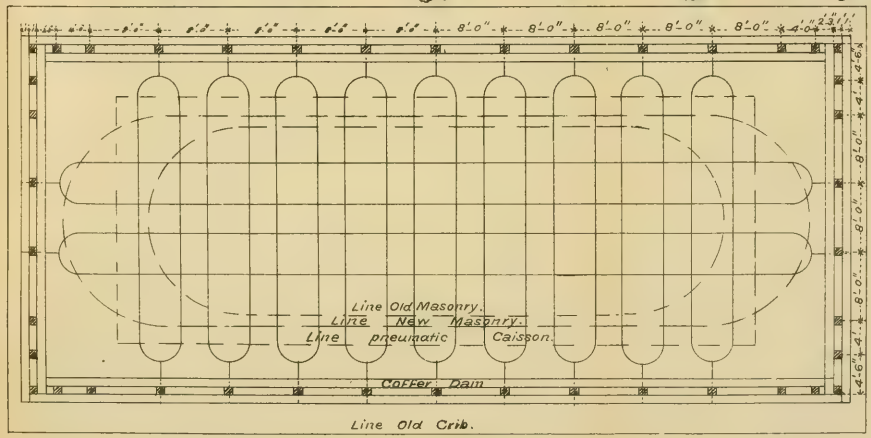



PLATE XLIX
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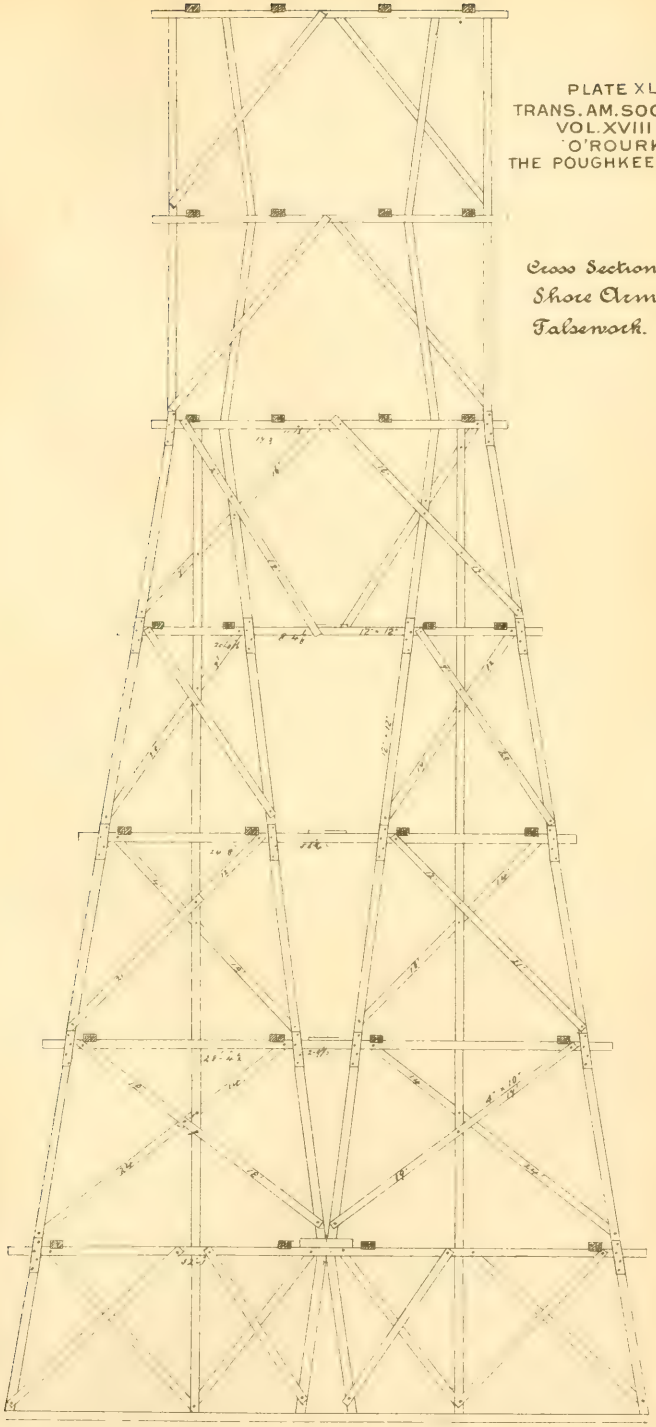
Cross Section
Shore Arm
Falsework.



Cross Section of Main False Work

Cross Section of Bridge.

PLATE L
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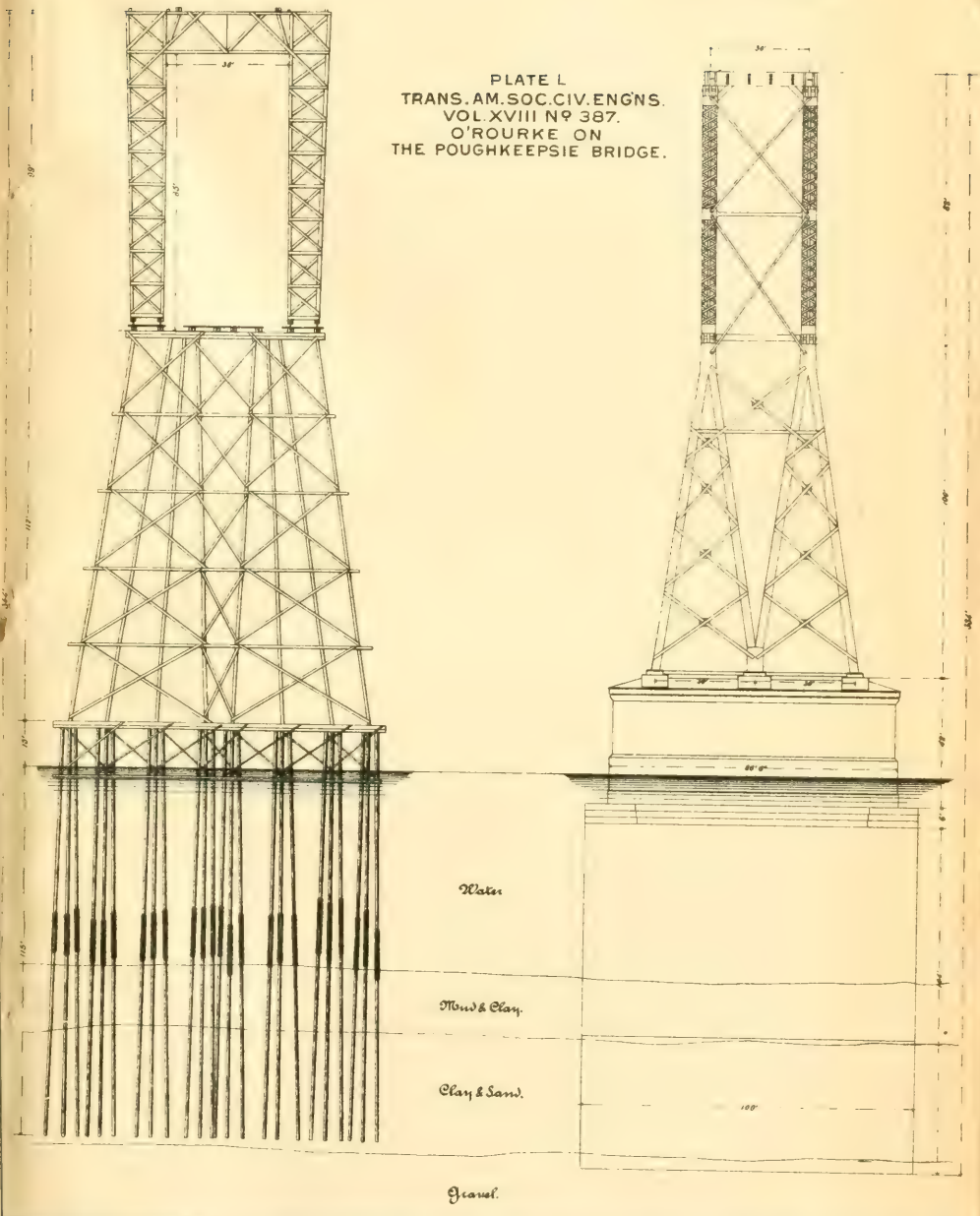
THE POUGHKEEPSIE BRIDGE.



Plan showing Method of Splicing Piles.

PLATE L'
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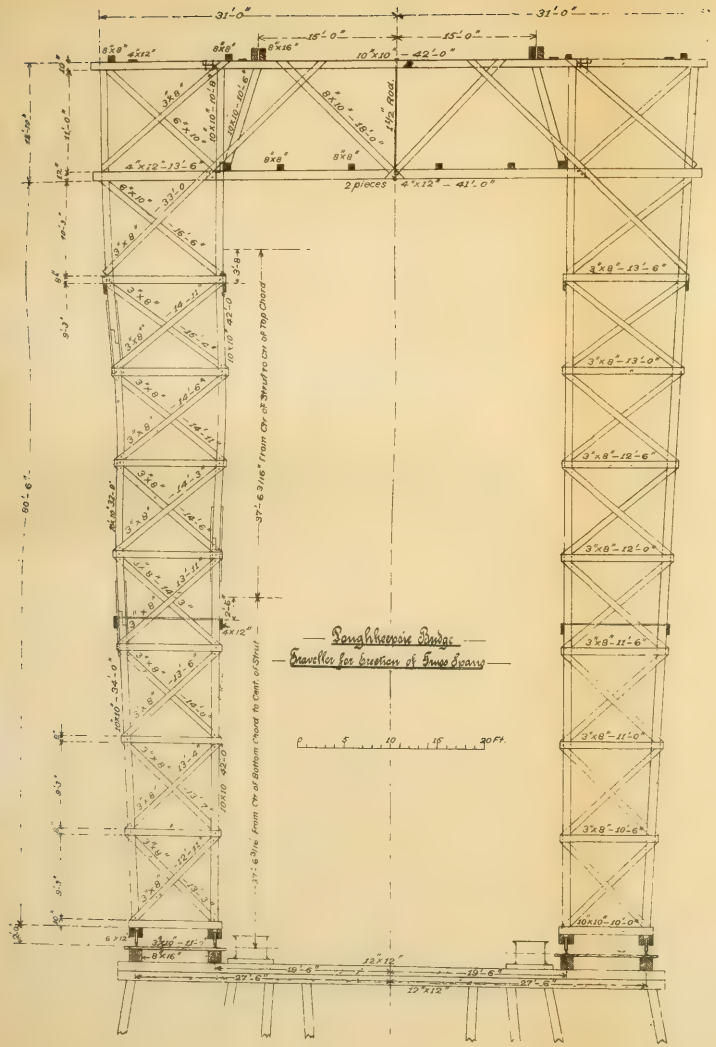
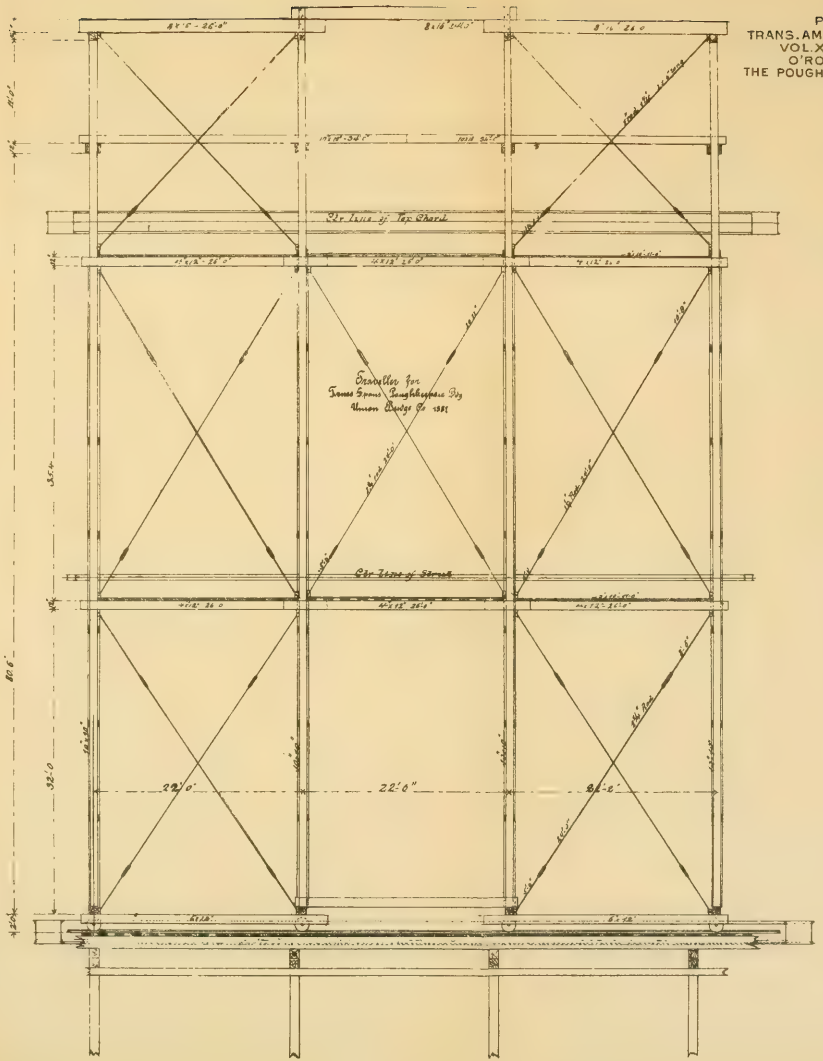
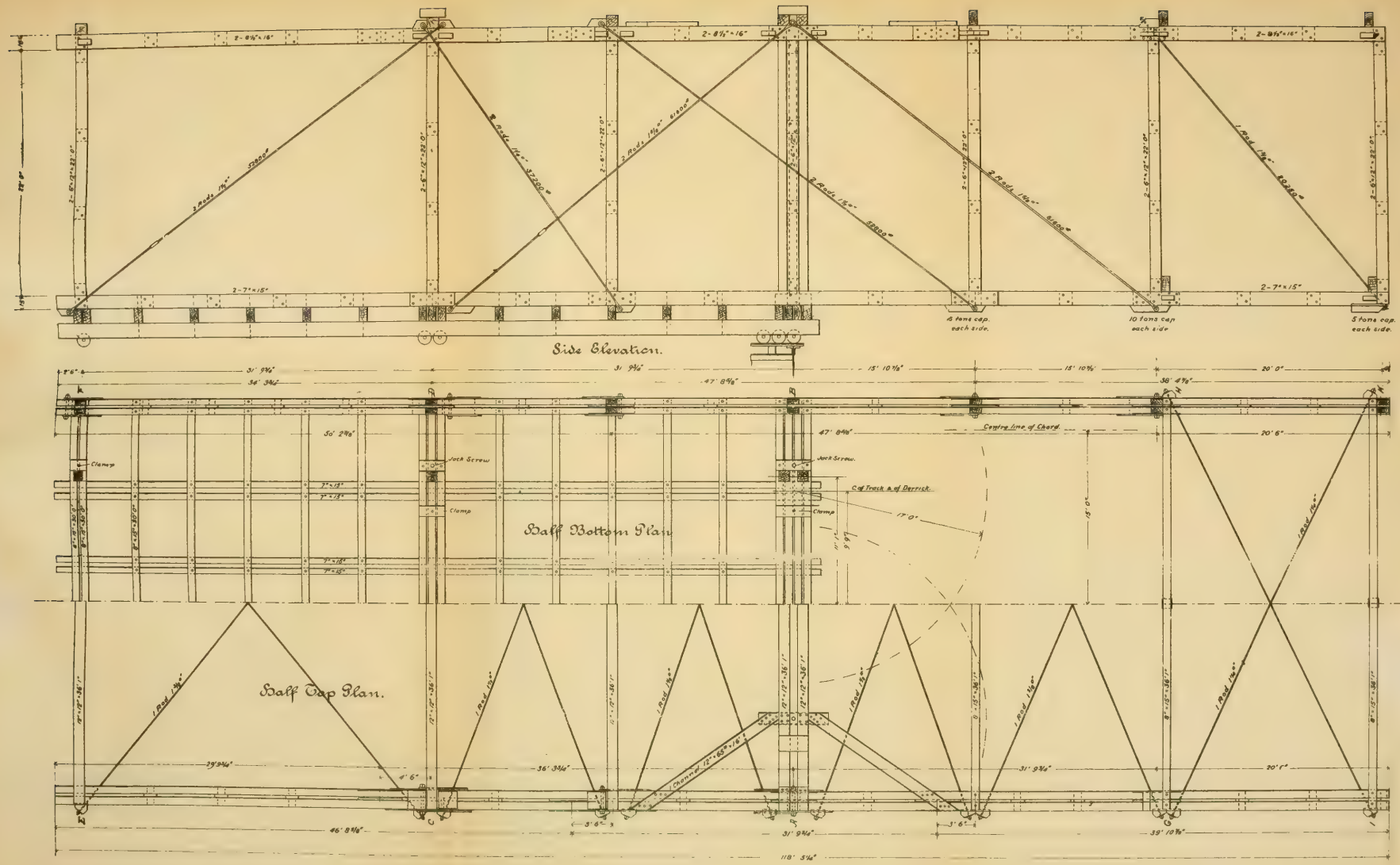
THE POUGHKEEPSIE BRIDGE.




Side Elevation.
Half Bottom Plan.
Half Top Plan.
Centre line of Chord.
Jack Screw.
Clamp
Cat Track in of Derrick.
17' 0"
15' 0"
5 tons cap. each side.
10 tons cap each side
5 tons cap. each side.
118' 5½"

# Twenty Ton Derrick

used in raising Materials to Top of Falsework.

## Poughkeepsie Bridge

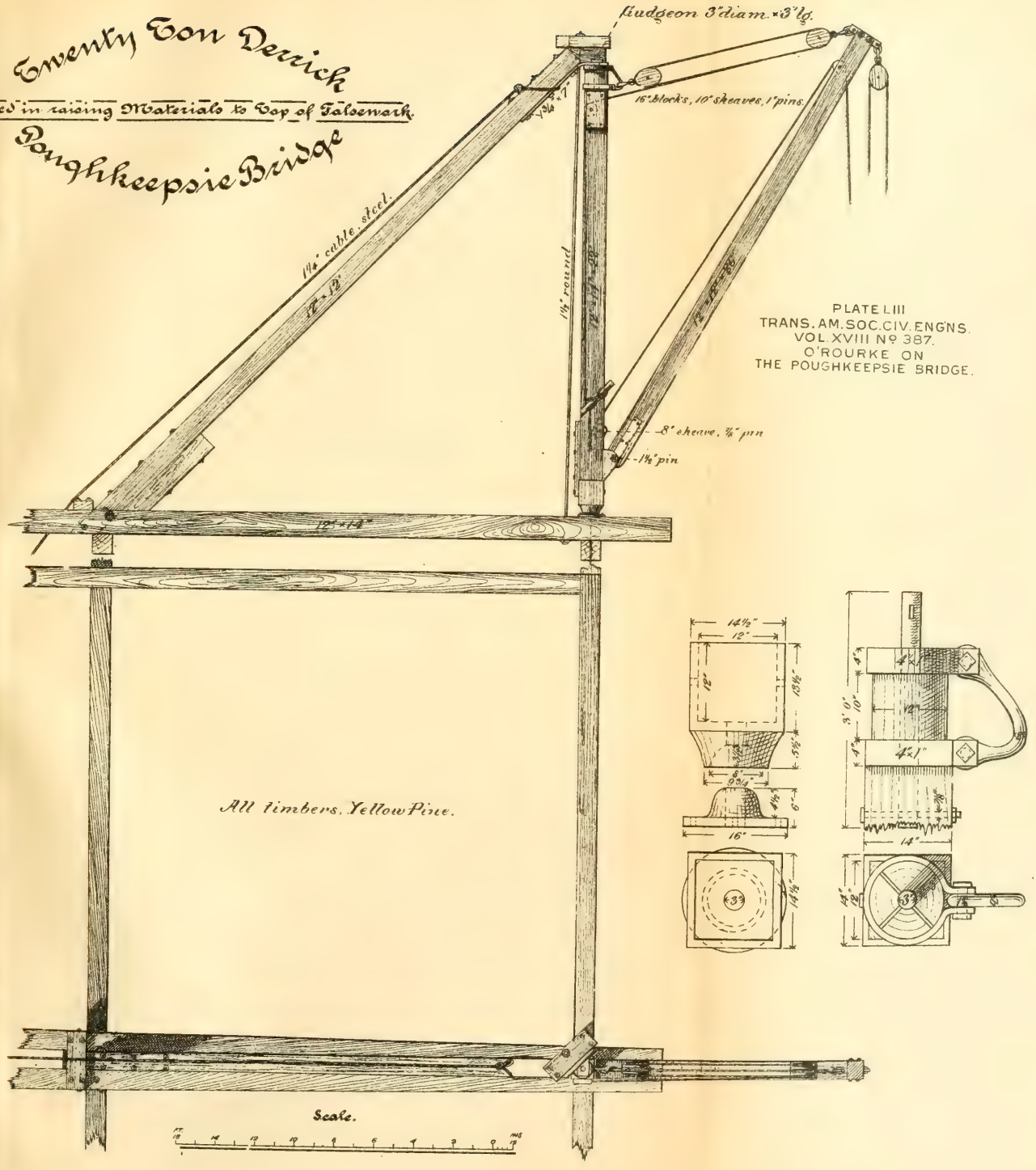



PLATE LIII
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PLATE LIV
TRANS. AM. SOC. CIV. ENG'NS.
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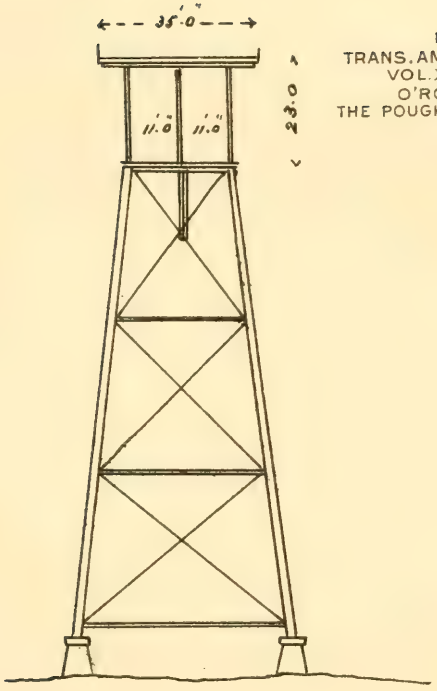


*Cross section of Viaduct*

PLATE LV
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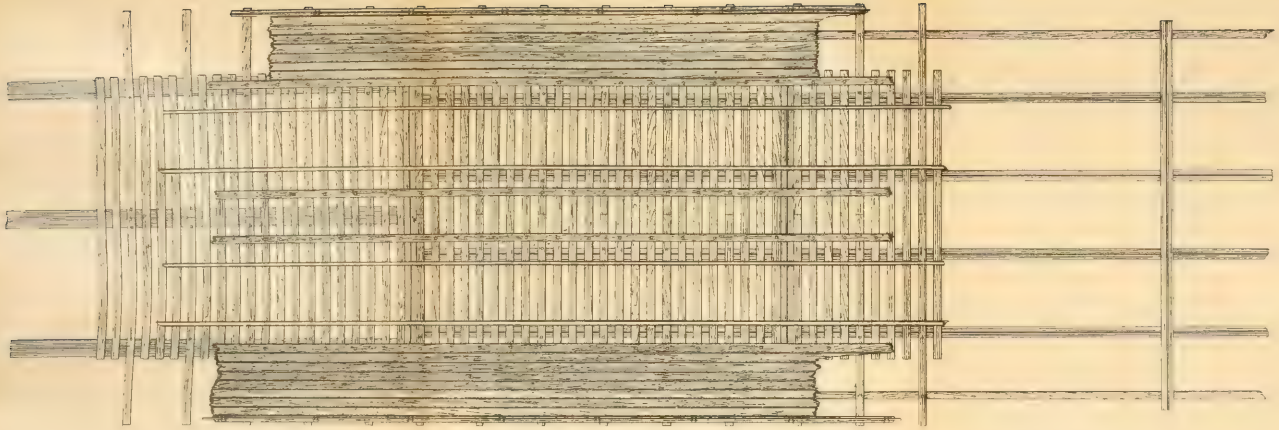
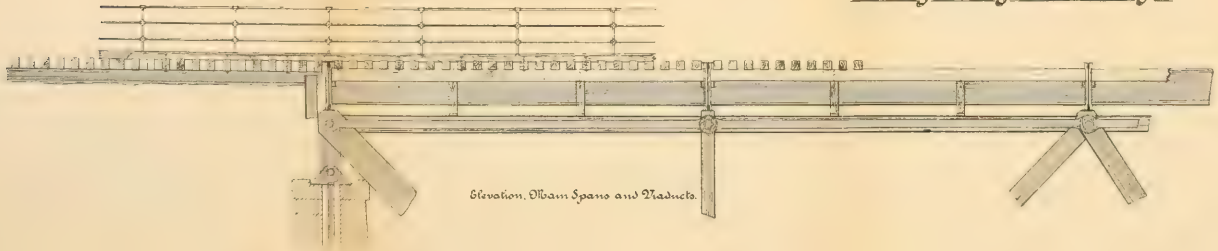
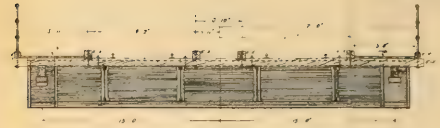


Plan, Main Spans and Viaducts.

# General Plan of Floor System of Poughkeepsie Bridge.



Elevation, Main Spans and Viaducts.



Cross Section, Main Spans.

Cross Section, Viaducts.

Hook Bolt. Scale 4"=1'.

Bill of Material

| Location | No. | Description | Size | Weight | Remarks |
|---|---|---|---|---|---|
| Main Spans | 4760 | Lower Floor Beams | 24"×16" under flange @ 2.58 | 12300 | 1 rivet & 1 slotted washer Steel under |
| Viaducts | 2800 | | 24"×17" | 7.68 | 7300 | 1 slotted washer |
| | 2800 | | 24"×19½" | 9.30 | 8420 | 1 rivet 1 slotted washer |
| Main Spans | 1180 | Stringers | 24"×21" | 3.18 | 3750 | 1 rivet under Steel Lower flange Plate with 8a |
| | 1180 | Lower Floor Beams | 24"×16" | 2.31 | 2700 | 1 rivet 1 slotted washer Steel under |
| Viaducts | 1380 | | 24"×18" | 2.70 | 3750 | 1a |
| Main Spans | 2400 | Lower Chord | 24"×24" | 3.00 | 4800 | 8" Pitch rivet 8" 1 rivet under |
| Viaducts | 1800 | | 24"×24" | 3.33 | 6300 | 8"Pitch |
| Main Spans | 100 | Shaft | 30"×30" | 2.50 | 1000 | For Stringer Seats |
| | 1600 | Lower Flange Splices 24" Plate | | | 16000 | |
| | 1700 | Steel | | 0.33 | 5700 | |
| | 303 | Misc. | | | 3000 | |
| Weight of Steel & Iron | | | | 0.33 | 75000 | |

| Description | Length | Spacing | Section | Weight | Remarks |
|---|---|---|---|---|---|
| Stringer Seats | 382 | 3'-0" | 8"×8" | 8272 | |
| Stringers | 748 | 30'-0" | 8"×17" | 37400 | Weight of 1 Stringer |
| | 44 | 30'-0" | | 2200 | |
| | 4 | 20'-0" | | 640 | |
| | 8 | 16'-0" | | 1254 | |
| Floor | 3300 | 24'-0" | 20"×44" | | Steel under |
| | 1380 | 17'-6" | | 103500 | |
| | 1788 | 24'-0" | 8"×8" | 12600 | Viaducts |
| | 1152 | 17'-6" | | 12960 | |
| Lower Floor Beams | 2850 | Weight to be | | 57000 | |
| Stiffening Rail | 840 | 21'-0" | 6"×6" | 12600 | |
| Plank | 6000 | 16'-0" | 3"×8" | 12000 | |
| Total for Bridge | | | | 1,263,272 | Pattern Iron |

PLATE LVI
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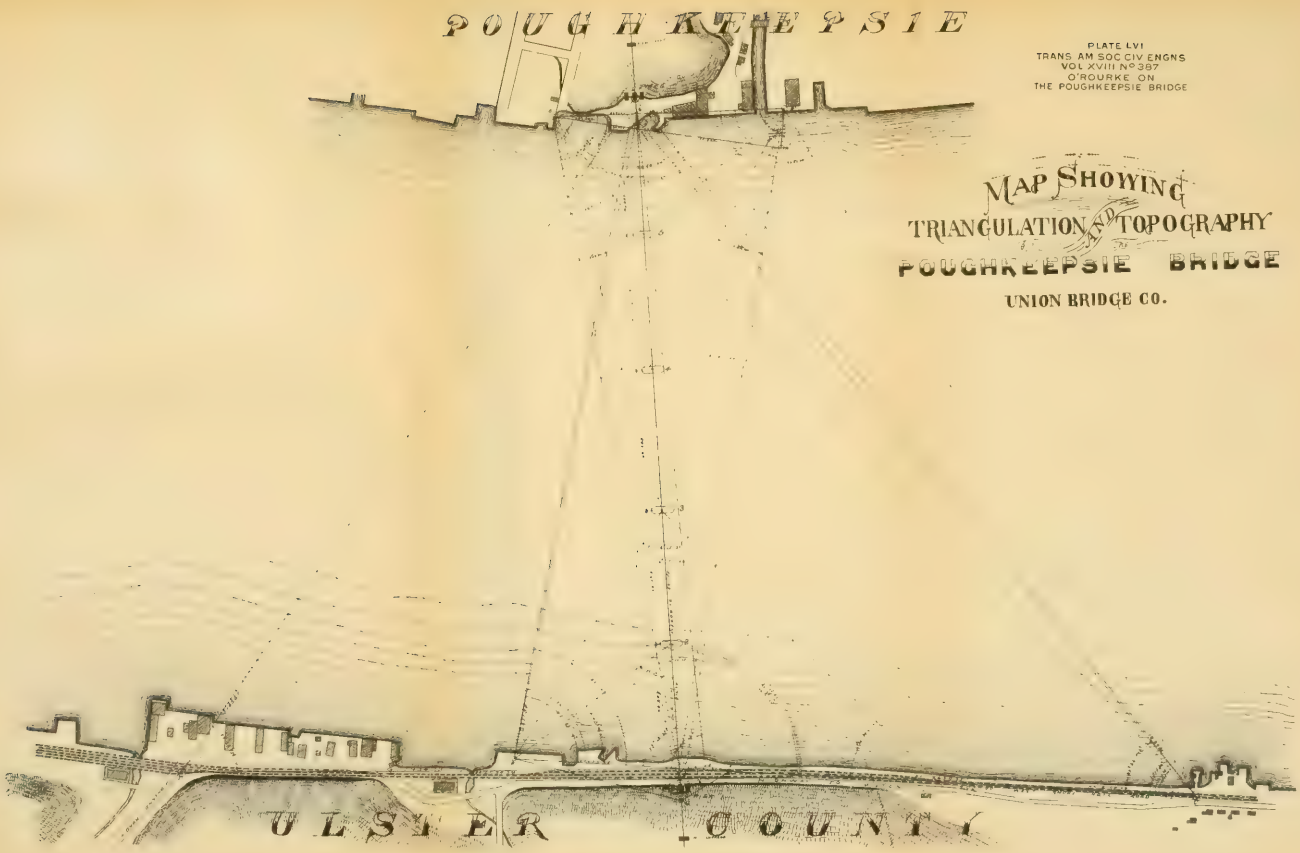
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE

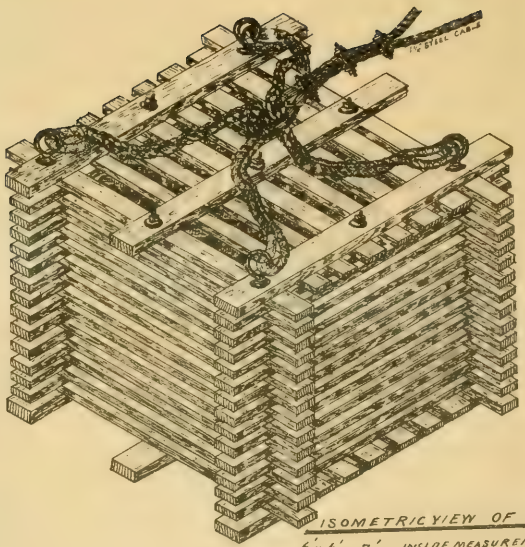



# MAP SHOWING TRIANGULATION AND TOPOGRAPHY OF POUGHKEEPSIE BRIDGE

UNION BRIDGE CO.

PLATE LVII
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII Nº 387.
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE.

METHOD OF LAUNCHING ANCHORS

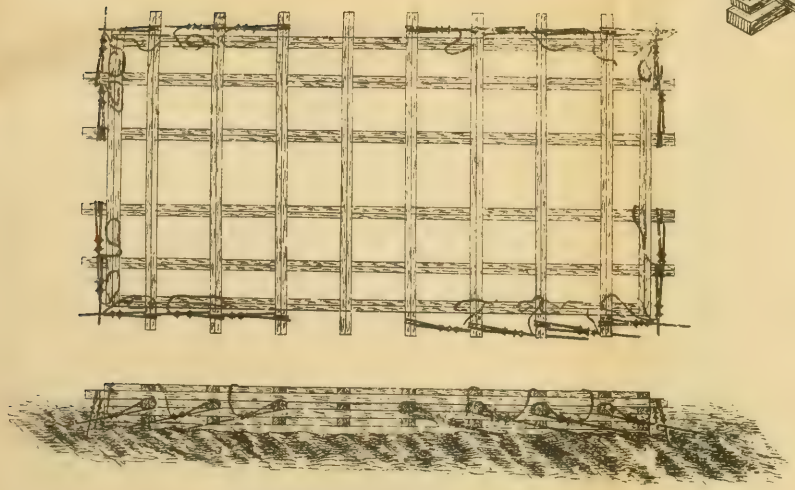



ISOMETRIC VIEW OF CHINEESE ANCHOR

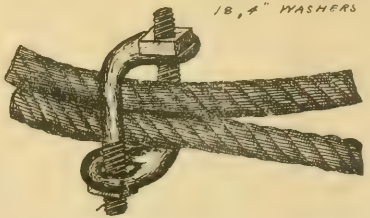
6'x6'x7' INSIDE MEASUREMENT LOADED WITH BROKEN STONE

BILL OF MATERIAL

52 HEMLOCK STRIPS 3"x6"x11'
6 " " 4"x9"x11'
12 " " 3"x4"x10'
4 IRON RODS ⅞" DIA 7'5" EYE W. WASHERS + EYE AT ONE END
5 " " ¾" 7'5" " "
18 4" WASHERS



CRIB, ANCHORED IN POSITION

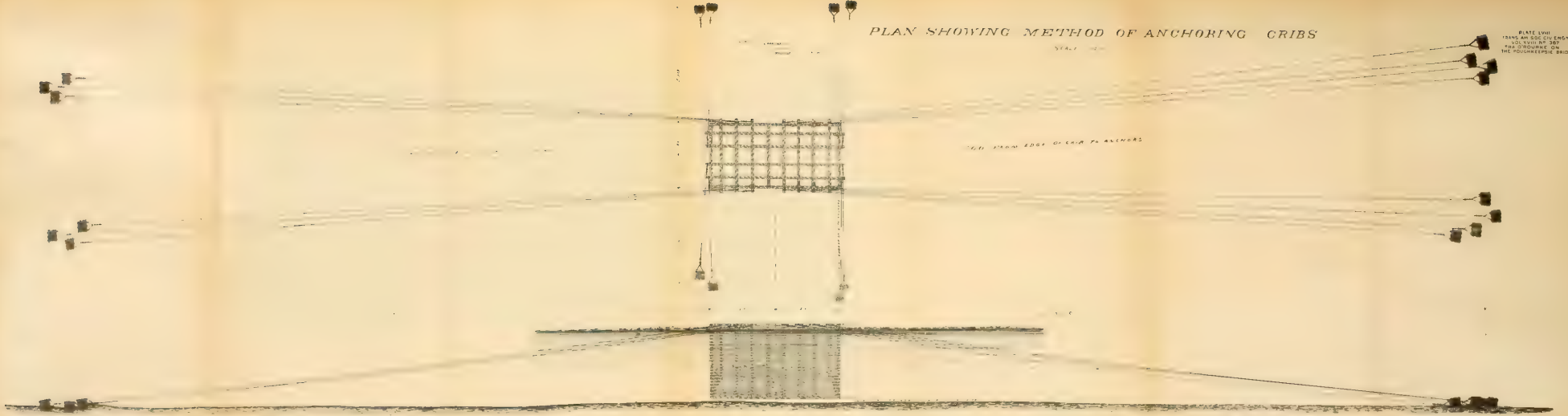


STYLE OF CLIPS USED

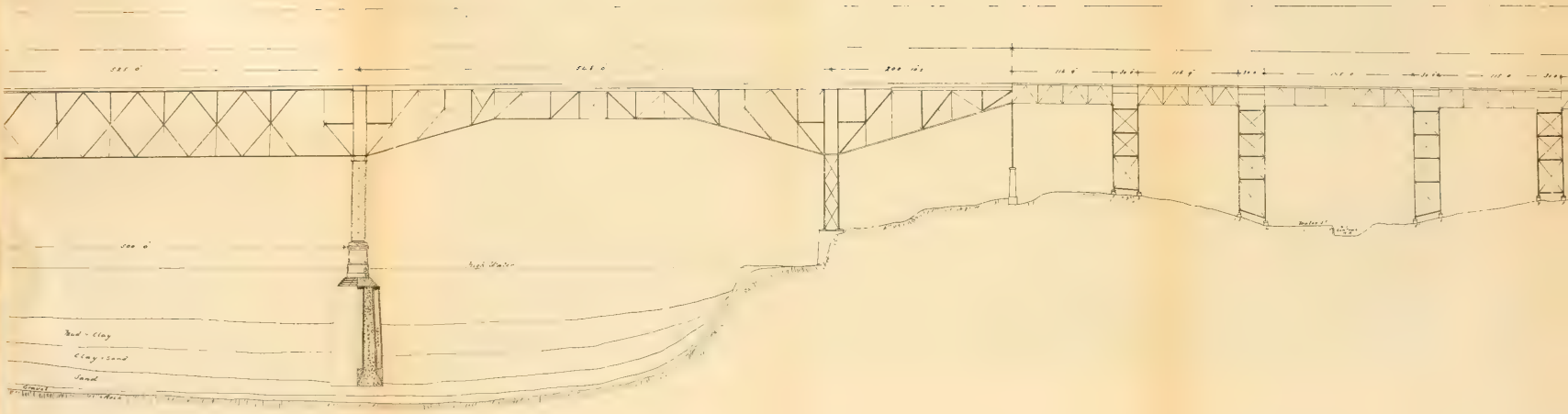
PLATE LVIII
TRANS. AM. SOC. CIV. ENGRS.
VOL. XVIII, NO. 387
PAUL GOURSE, CM.
THE POUGHKEEPSIE BRIDGE

# PLAN SHOWING METHOD OF ANCHORING CRIBS

SCALE

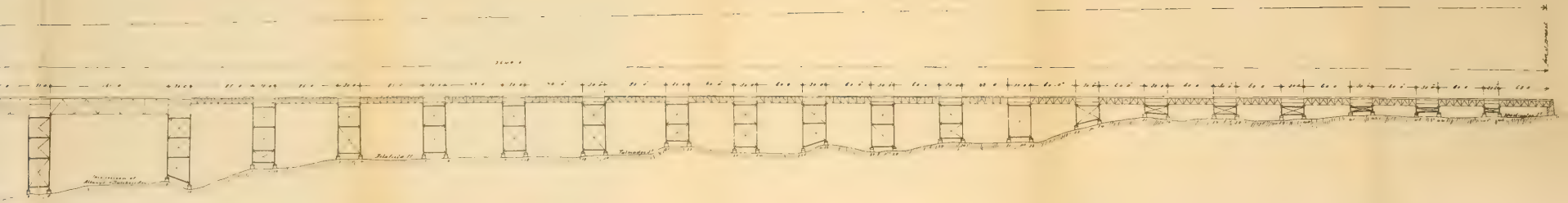


# GENERAL PLAN OF



# N OF POUGHKEEPSIE BRIDGE

PLATE LIX
TRANS AM SOC CIV ENGRS
VOL XVI NO 367
O'ROURKE ON
THE POUGHKEEPSIE BRIDGE



AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

388.

(Vol. XVIII.—June, 1888.)

# ENGLISH RAILROAD TRACK.

By E. E. RUSSELL TRATMAN, Jun. Am. Soc. C. E.

READ AT THE ANNUAL CONVENTION, JUNE 28TH, 1888.

American engineers, as a whole, are, I think, little conversant with the details of English railroad practice, and some few years ago I contemplated the preparation of an extended paper, or series of papers, on this subject, thinking that in this country, where railroads have reached a greater extent than in any other part of the world, such a paper would be of interest to the profession. The first part of this paper, on "Railroad Legislation in England," was published in *Engineering News*, August 1st, 1885; but in proceeding with the succeeding part I found, like many another man who has started out to accomplish something on a large scale, that I had undertaken too much, and had neither the time nor the material necessary for the work; and soon realized that the paper could not be prepared on the intended scale without considerable time being spent in personal investigation. This being impracticable, I abandoned so comprehensive a project and devoted my attention to the details of track matters; and while the English system does not commend itself, as a type, to many engineers outside of England, yet there are

some points which may be learned from it, and some details which might well be adopted as improvements on the average American practice. The details given are mostly obtained from official sources, and I wish to express my obligations to the engineers of a number of railroads in the United Kingdom, for courtesies received in the way of drawings, specifications and general information.

The standard type of English track consists of heavy rails carried in cast-iron chairs, which are attached to timber cross-ties. The rails are of two sections, viz.: "Double-headed" and "bull-headed;" the former section has two heads of similar form, connected by a web, and is intended to be reversible, although in practice this reversing is very rarely carried out; the latter section is simply a non-reversible double-headed rail, the disadvantages of reversing being recognized, and the lower head made only large enough to give a hold to the wooden key, or wedge, which is driven between the jaw of the chair and the web of the rail. These chairs, which weigh from 25 to 56 pounds each, give a wide bearing on the ties, to which they are attached by trenails, spikes or bolts. The ballast is generally broken stone, frequently with gravel boxing; broken slag from the iron furnaces is sometimes used, also burnt clay occasionally. Split switches are invariably used, the stub switch being unknown (except, perhaps, for contractors' tracks). Complete systems of semaphore signals, on the latest and most approved plans, are in general use, together with interlocking systems to a great extent; the block system of operation is generally adopted. Three features of railroad practice are: 1st. Heavy and careful construction; 2d. Complete equipment for safe operation; 3d. Care in operation and maintenance. Of course, accidents do happen, and would happen whatever care and precaution might be exercised, but they are far more rare than in this country (taking into account the difference of mileage). In fact, as far as safety of operation is concerned, I think the English railroads rank the highest in the world. This, of course, is without regard to the question of economy of construction, which is too little considered in England. The track is substantial and safe, but requires a large amount of unnecessary metal, and is unreasonably and unnecessarily expensive, a fact which renders it especially undesirable for introduction into the colonies and other new countries. The standard gauge is 4 feet 8½ inches, but the main line of the Great Western Railway is still 7-foot gauge, with a third rail for standard gauge rolling stock. Narrow gauges are

very rare. A space of six feet is left between the lines of double track roads.

The heads of English rails are very different from those of American rails. The majority of the older rails had rounded heads, formed by a succession of curves from the web to the top. The 82-pound double-headed rail of the North Eastern Railway is an example; also the 76-pound double-headed steel rail designed for the New South Wales Government Railways; the dimensions of the latter were as follows: height, 5¼ inches; width of heads, 2¼ inches; thickness of web, ½-inch; beginning at the middle of the rail the web was ½-inch thick for 0.92-inch, then it widened out by a curve of 0.55-inch radius, followed by a short tangent at an angle of about 30 degrees for nearly half an inch, then a curve of 0.59-inch, forming the side of the head and running into the curve of 5¼ inches radius which formed the top table. Other sections, such as the Great Northern Railway, 82 pounds, and the Great Western Railway, 86 pounds, have the sides of the head curved to a radius of about the width of the head, with top corners of large radius, about ¾-inch. A section much in favor now has vertical sides, with sharp top curves; the 85-pound rail of the Midland Railway is a good sample of this section; it is 2⅜ inches wide, radius of top table 5⅜ inches, radius of top corners, ⅜-inch, vertical part of side, ⅝-inch deep. The heads of the 79-pound flange rail and 75-pound bull-headed rail of the Great Northern Railway (Ireland) are 2½ inches wide, radius of top table, 10 inches; radius of top corners, ½-inch; vertical portion, $\frac{7}{16}$-inch deep; radius of bottom corner, ⅜-inch. I think it would be interesting to know how the wear of English rails and wheels compares with the wear of American rails and wheels. For comparative sections and dimensions of rails of different countries I would refer to an article of mine on "Rail Sections," published in the *National Car Builder*, New York, August, 1885.

Flange rails (or Vignoles rails, as they are universally termed in Europe), are not favorably considered for English railroads, although they have been tried on all classes of roads. Lines which were formerly laid with these rails have been relaid with the bull-headed rail, which is now the standard English rail section. It is a little difficult to understand this, when it is considered that the flange rail has been adopted as the standard section in all other parts of the world. The English system of double-headed rails in heavy chairs will undoubtedly make a very solid and durable track; but it is, in my opinion, too solid, contain-

ing much unnecessary metal and consequently entailing unnecesary expense. If this section is adopted, the rails must be supported in chairs, and, of course, these chairs do some good in distributing the weight over a large area of the tie, but this does not warrant the placing of 25 to 56 pounds of cast-iron at each end of every tie. To strike at the root of the matter, however, I believe the double-headed rail (and in referring to this section I also include the bull-headed section) to be, in the light of modern experience, unscientific and unnecessary. The original idea was brilliant—to make one rail do the work and last the life of two; this was plausible, but in practice it was not successful, for the weight of the traffic caused the lower head to be indented at its seat in the chair, so that riding was very rough when this head was put into service. Different methods of obviating this defect were tried; in some cases, as on the North Eastern Railway (Plate LX), wooden cushions were placed between the rail and the chair; in other cases the rail was suspended in the chair, being supported by the under side of the rail-head resting on the jaw of the chair. This latter method was adopted originally on the London and North Western Railway, and is still in use to some extent in India, and a somewhat similar plan was suggested by Mr. W. Bridges Adams, the inventor of the fish-plate. The result of these endeavors, however, may be guessed from the general adoption of the bull-headed, non-reversible rail.

Even if it is conceded that the English type of track, as now in use, is safe and substantial, and adapted to the requirements of traffic on English roads, it was surely a most ill-advised proceeding to introduce it in the colonies. Yet, in India, it was extensively introduced, and in 1876 a track was designed by Mr. John Fowler, M. Inst. C. E., for the New South Wales Government Railways, which consisted of 76-pound double-headed steel rails in 26-pound chairs. In this way the colonies were likely to be overwhelmed with capital expenditure, and it is easy to see what a much greater extent of country might have been developed and made productive by the use of a track lighter and less costly, but equally efficient for traffic requirements. With a flange rail there would be 52 pounds of cast-iron (chairs) per yard saved, or 91 520 pounds per mile, while a 65 or 70-pound rail would have been amply heavy enough, especially with the English system of fastenings; in fact, a 71½-pound flange rail was designed for this same system. The flange rail, however, is now extensively used in all the colonies, and will probably

supersede the double-headed rail entirely; this latter form of rail is still in use in India, and has even been introduced into South America by English engineers, generally in conjunction with cast-iron "pot" sleepers. The following are the weights of some English rails for the colonies, etc.: Queensland, 41¼ pounds per yard flange rails for a gauge of 3 feet 6 inches; South Australia, 50 and 61 pounds per yard flange rails for gauges of 3 feet 6 inches and 5 feet 3 inches respectively; India, from 41¼ pounds per yard flange rails for 3 feet 3⅜ inches gauge, to 75 pounds for 5 feet 6 inches gauge, also double-headed rails of about 70 and 75 pounds per yard for 5 feet 6 inches gauge; South America, 58, 67 and 70 pounds per yard flange rails, and 50 pounds per yard bull-headed rails (resting on wooden cushions in cast-iron chairs) for a gauge of 5 feet 6 inches. Had the "rail and chair" type of track been generally adopted, the colonies would have built the railroads for posterity, reaping little practical benefit during the youth of the country. Had the promoters of an American transcontinental line waited until they could build a road of the standard of the Pennsylvania or the New York Central, I fear the Panama Railroad would be in a condition to put down a double track of 100-pound rails with cast-iron chairs, and perhaps there might be some American enterprise in the canal scheme. In this country the tracks are adapted to the requirements of the roads, and although there are many lines with too light a track, yet there are many excellent tracks on the busy Eastern roads, and the improvement of the tracks is following the increase in traffic, which is true economy. I would like to note the fact that weight is not the only essential for rails of busy roads; good design and good manufacture are equally necessary, and as an instance of the necessity of good design, I may say that the Panama Railroad was originally laid with 56-pound rails (four inches high); a heavier rail was considered necessary a few years ago, and the weight was increased to 70 pounds, but the extra metal was principally used in thickening the web, giving but a slight increase in stiffness.

In Ireland the flange rail is very generally used, and is very favorably spoken of by the engineers of some of the principal lines, although the bull-headed rail is stated to be advantageous on curves, as giving better results in maintenance and efficiency. Some rail sections and details of the track of Irish railroads will be found on the accompanying plates; and I desire especially to call attention to the fastenings, which are

decided improvements upon the universal but inefficient spike fastening of American practice.

In my correspondence with the engineers of English lines I have been particular to ask for their views on the respective merits of double-headed and flange rails, and the replies have been very unfavorable to the latter, the points made being that they will not stand under heavy traffic and high speed.

Mr. Forrest, Secretary of the Institution of Civil Engineers, says: "The Vignoles pattern rail was used a good deal by contractors who made cheap railways, but it has been universally condemned and taken up, as the fastenings soon worked loose, and the rails would not keep to gauge. It has the further disadvantage that a bad rail is not so easily changed as one fixed in chairs. The Vignoles rail, as used in this country (England), weighed from 60 to 75 pounds per linear yard; the Metropolitan, of course, more.* It was from 4½ to 5 inches high, and from 4 to 5 inches broad in the bottom flange, according to the fancies of the constructing engineers. This form of rail is used generally on the Continent, but most continental engineers are believed to prefer the double-headed rail with chairs, and are only prevented from using it by reason of the extra expense.† The railways on the Continent have the advantage of hard-wood sleepers, which hold the rail fastenings better than the piné sleepers universally used in England."

Mr. Conner, formerly engineer of the Isle of Wight Railway, a line on which 70-pound flange rails, 4¼ inches high, with 5¼-inch base, have been replaced by 78-pound double-headed rails, writes as follows: "The rails are reversible, but are not turned over, experience showing they are then rough to travel over and more liable to break. I strongly recommend bull-headed rails, and for heavy traffic know of none better than those of the London and North Western Railway, which are 90 pounds per yard. * * * Spikes are not reliable for flange rails."

Mr. Owen, engineer of the Great Western Railway, writes as follows:

* The flange rail used on the Metropolitan Railway, London, was 4.2 inches high, with a base 6⅜ inches wide; it has, however, been replaced with a bull-headed section.

† I cannot think that Mr. Forrest is correct in this remark, as the flange rail is almost universally adopted on the Continent, even on State railway systems, where a little extra cost would not prevent the adoption of a specially good form of rail. Many of the double-headed sections used on the Continent have been of bad and clumsy design, resembling an hour-glass in section. Heavy flange rails are the most modern type adopted and approved, which is a step in the right direction.

"Flange rails are very seldom used, only on country lines with four or five trains a day; they cut into pine sleepers and are very troublesome to maintain. The Hammersmith and City line* has been relaid with chairs and rails. The double-head is not now laid, all relaying is bull-head."

Mr. Bayley, Engineer-in-Chief of the Great Southern and Western Railway (Ireland), on which 74-pound flange rails are used, writes: "Consider bull-head best where traffic is heavy."

Mr. Keeling, engineer of the Severn and Wye and Severn Bridge Railway, a road which has several grades of 1 in 40, and one of 1 in 30 followed by 1 in 31, the two aggregating about 2½ miles in length, with some sharp curves, writes as follows: "We found that the flange or Vignoles rail was troublesome and expensive to maintain and keep in order on a line where the gradients are steep, curves sharp, and on which tank engines weighing (loaded) nearly 50 tons, are employed. We have therefore relaid the greatest portion of our line with the double-headed steel rail. I scarcely know any line of importance in England that continues to use the Vignoles rail on the main line."

Mr. Price, for fifteen years Chief Engineer of the Midland Great Western Railway (Ireland), writes as follows: "I believe as safe a road can be made of this (flange) rail as it is possible to make." He uses very efficient fastenings, as will be seen further on, and says: "This system is cheaper and safer than a double-headed rail or a bull-headed, but these latter are a little steadier and more silent. I do not believe in turning rails, so prefer a bull-headed to a double-headed rail." In another letter he says: "The general opinion is strongly in favor of flange rails, as being cheaper and nearly as steady as the double-head or bull-head."

Mr. Mills, Engineer-in-Chief of the Great Northern Railway (Ireland), writes as follows: "We use the bull-headed section on those parts of the line on which heavy curves and inclines exist, because this section of rail is more easily bent, and retains the curve better than the flange, and when laid in the cast-iron chairs and secured with the heavy fastenings, it forms a stronger road than the flange rail. The comparative cost is as 3 to 4, the chair road being the more costly." This road

* The Hammersmith and City line, which is a London suburban branch, was formerly laid with flange rails weighing 69 pounds per yard, having a base of 5⅛ inches, a height of 4½ inches, and a head 2½ inches wide.

has 139½ miles of double track, and 382½ miles of single track; total, 661½ miles, of which 106 miles are laid with the steel bull-headed rail.

Mr. Langley, Engineer-in-Chief of the Midland Railway, wrote as follows: "You have, I think, a great quantity of this (flange) section of rail in your country; doubtless, it was suitable for the light traffic, but as the loads have increased, I understand that you have suffered very much from broken rails. These breakages have, I think, been wrongly attributed to defective material, but are really the result of a defective design." In a later letter, replying to one in which I referred to the heavy and rapid traffic carried safely over the fine tracks of Eastern trunk lines, he wrote as follows: "Under the great velocities and heavy weights on the driving wheels of our engines, I think the road would be broken up in a few hours; in fact, in some cases it would not stand the passage of a single train."

This, of course, is largely a matter of prejudice, as the flange rail is used successfully for very heavy traffic, and in fact, this section, as a type, is now the standard section of the world, being a case of the survival of the fittest, improved upon by successive generations. On the other hand, it is pleasant to hear the general approval from Ireland, especially from Mr. James Price, the veteran railroad engineer, though even he says that flange rail track is "nearly" as steady as the double-head or bull-head; and even Mr. Sandberg, a strong advocate of the flange rail, says that speed has something to do with its non-adoption in England. So much testimony, from so many sources, must needs have some truth, and I think the explanation may be looked for in the locomotives and rolling stock. Although there are a large number of engines on the American plan, with a leading truck, and many cars on four and six-wheeled trucks, yet the majority of the equipment consists of passenger engines with a single pair of small leading wheels, with rigid axle (the total wheel-base being rigid); freight engines with six wheels, all coupled, and cars with two or three rigid axles. Such an equipment must undoubtedly be harder on the track than the "adjustable" American type of engines and cars.

The Pennsylvania Railroad has four sections of the London and North Western Railway standard track laid for experimental purposes. The rails weigh 90 pounds per yard, and two of the sections are laid with the steel cross-ties and chairs, while the other two are laid with wooden ties and cast-iron chairs. Some years ago, about ten miles of track on the

Boston and Worcester Railroad (now a part of the Boston and Albany system) were laid with 80-pound double-headed iron rails, carried in chairs weighing 28 pounds each. The rails were rolled at Worcester, Mass. The ties were spaced about 3 feet center to center. The joints were even and suspended; they were spliced with fish-plates and common bolts and nuts. The rails were secured by wooden keys, driven in solid and secured with a nail to each key. One defect of the track was the frequent breaking of the chairs. After ten years' service the track was relaid with flange rails.

An objection to the flange rail, and one which is strongly urged by its opponents, is that it cuts into the ties; this, however, can be easily prevented by the use of sole-plates, which are certainly cheaper than chairs. Mr. J. W. Post, of the Netherlands State Railroad Company, has had satisfactory results from the use of sole-plates with sharp teeth on the underside, which bite into the wood and prevent slipping; these plates are fastened by square-headed screws, which grip the flange of the rails.

The track accidents in this country may generally be attributed to bad condition of the road-bed, bad rails, inefficient fastenings and especially to the use of too light a rail. Mr. C. P. Sandberg, the designer of the 110-pound "Goliath" rail, shows in his paper on "Rail-Joints and Steel Rails" (Proceedings of the Institution of Civil Engineers, Vol. LXXXIV, 1886), that traffic which requires an 80 or 90-pound bull-headed rail in 40-pound chairs, would require a 100 or 110-pound flange rail. The 110-pound flange rail has already been adopted by some roads on the European continent, and large contracts for further supplies have recently been given out. The need of heavier rails is being recognized in this country, and in fact the more important lines are gradually introducing them.

If the English railroad companies or engineers would adopt a well-designed, heavy flange rail, and give it good joints and good fastenings, I think there can be little doubt that they would have a track fully as safe and efficient as with the present system, and costing no more for maintenance, but effecting a considerable saving in first cost, and built on more scientific principles. Mr. Sandberg, in a letter, states that speed has something to do with the rejection of the flange rail, but that if these rails are given the same chances as the others in weight, better results will be obtained for less money. As to the matter of speed,

however, there is traffic fast and heavy enough in this country, especially on the principal lines of the Eastern States, to prove the capabilities of the flange rail. The track should be designed for the traffic. Sole-plates might be used to prevent the rail from cutting into the ties, and if there is fear of the track spreading, tie-rods might be put in to hold the rails together on curves or at other points.

### Rail Tests.

The following are the tests given in the specifications of the railroads mentioned, and full-sized sections of the rails are shown on the accompanying sheet of rail sections. (Plate LXIII.)

*Great Northern Railway.*—(Steel rail, bull-headed section, 82 pounds per yard.) "A piece of rail 5 feet long shall be cut off and placed directly on solid iron bearings 3 feet 6 inches apart in the clear, fixed on a solid cast-iron block well bedded, and shall then receive successive blows from a weight of 1 120 pounds, falling from a height of 10 feet. Should the rail break before or under the third blow, or should it take a permanent set after the first blow, exceeding $1\frac{3}{4}$ inches, the whole of the parcel from which it has been selected will be rejected."

*Midland Great Western Railway (Ireland).*—(Steel rail, flange section, 79 pounds per yard.) "Each selected rail will be placed in the usual position, on bearings 3 feet 6 inches apart, and a weight of 18 tons will be applied on each rail at the center, between the bearings, and the deflection must not exceed $\frac{3}{4}$ of an inch after the weight has been applied for half an hour, and after the weight has been removed the permanent set must not exceed $\frac{1}{4}$ of an inch. The next test each rail will be subjected to is as follows: Placed in the usual position, on bearings 3 feet 6 inches apart, a ball weighing 18 hundred-weight (2 016 pounds) will be dropped upon each from a height of 8 feet, and each rail must bear two such blows without breaking and without deflecting more than 1 inch. The bearings on which the rails are to be tested to be of timber 12 inches square, 6 feet long and laid on solid hard ground. The rails to be held down to timbers by dog-spikes."

*South Australian Government Railways.*—(Steel rails, flange section, English manufacture).—The rails are to be placed upon supports 3 feet apart, must stand four blows of the drop test without breaking, and the dead-weight test must continue for ten minutes without causing permanent deflection. The bearings upon which the rails are to be tested must be formed with a radius of 12 inches, and form part of a block of cast-iron weighing not less than 2 tons. The block must be securely and properly bedded upon a solid foundation of concrete; the bottom of the "tupp," or falling weight, must be of the same form as the bearings of the block. The tests are as follows:

Drop Test.

| Rails. | Weight. | Fall. |
|---|---|---|
| 41-pound. | 784 pounds. | 10 to 16 feet. |
| 50- " | 1 120 " | 8 to 12 " |
| 61- " | 1 120 " | 10 to 16 " |

Dead-weight Test.

| Rails. | Weight. | Time. |
|---|---|---|
| 41-pound. | 10 tons. | 10 minutes. |
| 50- " | 12 " | 10 " |
| 61- " | 15 " | 10 " |

Should the inspecting engineer consider it desirable to have any check tests made in London at the public testing machine, the contractor must pay the cost of such test.

Specifications for Rails.

The contractor is usually required to furnish rails which will stand certain tests, but is not bound to any special chemical properties of the material. The following are extracts from specifications in the writer's possession, and attention is called to the guarantee clauses.

*Great Northern Railway.*—The rails are to be of the bull-headed section, and an exact template will be furnished to the contractor. The rails must be made wholly of steel of the very best quality manufactured for rails by the Bessemer process. They are to be made of Nos. 2 and 3 hematite pig in equal quantities, to be remelted in cupolas, it being distinctly understood that neither Northamptonshire, Lincolnshire nor Cleveland pig will be allowed. The rails are to be made and rolled in England. Each rail shall be made from a single ingot, which shall be perfectly solid and regular in quality, and free from defects of every kind. The ingots to be subsequently thoroughly heated and reduced by being hammered to such an extent as may be deemed necessary by the company's engineer, before being rolled to the correct form. The rails must be sawn off perfectly square to the requisite length, and the ingots in all cases must be of ample length to insure a long crop being cut off, clear of the least appearance of scallops, at both ends of the rails; and should any imperfection in the quality, or unsoundness arising from gas cells, cold shuts, or otherwise, be apparent, either in the

ingots or during their subsequent treatment, such ingots or rails will be rejected and set aside as not being admissible under the contract. The rails when finished are to be in every respect perfectly sound and homogeneous, free from flaws, blisters and other defects, and perfectly straight. The rails are to weigh 82 pounds per yard, and none which either exceed or fall short of that weight by more than 1 pound will be accepted. The rails are to be cut to the exact length of 30 feet; the engineer, however, will receive for the contractor's convenience, a few lengths in even feet from 12 feet upwards, but together not exceeding 5 per cent. of the whole quantity. Each rail is to have at each end of it two holes, 1¼-inch by 1-inch, drilled truly to a template and gauge; no punching will be allowed. Each rail is to be marked G. N. R., with the initials of the makers, name of the works where they are manufactured, and the month and year when supplied. The contractor must provide the apparatus required for applying the specified test. The contractor is to deliver as directed by the engineer, in exchange, without charge to the company, a new rail of as good quality and make as those he delivers in the first instance, for every rail which, until twelve years after the date of the last delivery, shall become crushed, bruised, broken or seriously worn, whether the same be caused by ordinary or increased traffic, by the application of brakes, or by whatever cause (accident alone excepted); and should any rail supplied in lieu of an injured rail become injured as above described, the contractor shall continue to supply new rails in exchange as many times as the rails become injured in wear as above described, until the expiration of the term of the guarantee.

*Midland Great Western Railway (Ireland).*—The rails are to be rolled perfectly true and uniform throughout to the section shown (flange section; Plate LXIII), to be straight and out of twist, smooth onthe surfaces, free from flaws or imperfections, and care must be taken that every rail is cooled in such a manner as to insure a proper temper. The weight to be 79 pounds per yard, none accepted weighing less than 78 pounds, and no allowance for any weighing more than 80 pounds per yard. Each rail is to have two oval holes punched at each end, as shown; these holes are to fit perfectly the fish-plates, when in their proper position, and no variation in either the position or size of holes exceeding $\frac{1}{32}$ of an inch will be allowed. Each rail is to be stamped on both sides of the web, near the middle (but not opposite), with the letters M. G. W. R., the maker's name and year of manufacture. The material out of which the rails are to be rolled, to be tough Bessemer steel of uniform character. The fish-plates are specified to be made true, uniform and perfect in every respect, of iron of a tough quality, capable of bearing a minimum tensile strain of 22 tons per square inch, and to stretch 10 per cent. in length before fracture. The plates to be cleanly punched from the inside, in pairs, alternately with square and round holes and to fit perfectly the sides of the rails.

*South Australian Government Railways.*—The rails are to be made from ingots large enough to make one or two rails, and the contractor must state whether they will be made by the Bessemer or Siemens' process. If by the Bessemer process, the ingots are to be made of the most approved mixture of hematite pig, all to be remelted in the air furnace before being subjected to the Bessemer process. If by the Siemens' process, the ingots are to be made of the most approved mixture of hematite pig, with the usual percentage of scrap steel added, and during the time the metal is in the furnace care must be taken to introduce such a mixture of spiegeleisen, etc., as shall insure an ingot of the hardest and toughest metal for the purposes of rail making. Each rail should be made from an ingot not less than 10 inches square at the smallest end, and of sufficient weight to allow all the unsound parts to be cut off each of the rails. The ingots are to be cogged into a perfectly sound and compact bloom. The fish-bolt holes, oval, are to be drilled. The rails are to be 30 feet long; those for the inner side of curves to be 29 feet 8 inches long. The manufacturer must ascertain and inform the inspector daily of the percentage of carbon in the rails, to enable him to report to the inspecting engineer. The fish-plates are to be rolled from first quality of Bessemer or Siemens' steel, suitable for the purpose and equal to the rails. The guarantee for rails and fish-plates is for a period of six years.

## Fastenings.

One detail in which English track is superior to the average American track is that of the fastenings; and this detail is one of such vital importance for the efficiency and safety of the track, that it is worthy of very careful consideration. With the exception of a few cases, where some improved device has been adopted, such as the Bush interlocking-bolts on a part of the New York Central, the rails on American lines are held down only by the spikes, and for this reason accidents caused by the spreading of the track or overturning of the rails are very common. The ordinary spike cannot and does not hold under heavy traffic, and any one who cares to make a little observation can learn some very startling facts on the matter of rail fastenings.

The chairs for the double-headed rails in England are usually fastened to the ties by spikes, plain wooden trenails, compressed trenails (which expand and form a very tight fastening), or hollow trenails, which are first driven into the hole bored in the tie and then have a round spike driven into the hole. On the Great Eastern Railway the trenails are $6\frac{1}{4}$ inches long, $1\frac{1}{4}$ inches diameter for about 4 inches from the bottom, and then widen out to $1\frac{5}{8}$ inches diameter at the top. The spikes are round, $\frac{7}{8}$-inch diameter and $5\frac{1}{2}$ inches long under the head, which is hemispherical. The London and North Western Railway has its chairs

fastened by two plain spikes and two galvanized screw-spikes (three threads to the inch); the latter grip the chairs by means of wooden ferrules placed in the hole, through which the screws pass; the heads of these screw-spikes are hexagonal. The rails are secured in the chairs by wooden blocks, called "keys," driven horizontally between the web of the rail and the jaw of the chair; they are usually about 3½ inches high by 2½ inches wide and 7 inches long, sometimes taper and sometimes of uniform section. The London and North Western Railway uses a chair with four horizontal grooves in the face of the jaw, the ridges biting into the wooden key and preventing it from slacking back. The keys are driven, when possible, in the direction of the traffic, and are usually on the outside of the track; but some lines have them on the inside. Iron keys, made of a strip of iron coiled spirally, with a slight taper, to the form of the cross-section of an ordinary wood key, are used to a small extent.

But what is of more interest and importance to American engineers is the way in which the flange rails are fastened to the ties. The principal feature is the almost universal use of the fang-bolt, a very efficient form of attachment. These bolts are used at joints and at one or more intermediate points; there is a fang-nut at the under side of the tie, and the edges of this cut into the wood, so that the bolt can be screwed up from the top. In some cases the bolt passes through the flange of the rail, in other cases it holds the flange by means of a clip or crab; the former method is objectionable on account of expense and of trouble in adjustment. Screws, square (dog-headed) spikes and jagged spikes are used, in conjunction with the fang-bolts, at intermediate ties. On the Midland Great Western Railway (Ireland), ordinary bolts and nuts are used, but the nuts of the two bolts to each rail fit into a piece of channel iron on the underside of the tie, which prevents their turning; this arrangement is shown on one of the plates. With regard to this fastening Mr. Price writes as follows: "I fasten down with three pair of sole-plates to each pair of rails, one pair on each end and one pair on the center sleeper. The bolts fastening down are very large, for first-class railway $1\frac{1}{16}$-inch diameter, outside flange, or rather $\frac{1}{4}$-inch on flange, with washer on top gripping the rail. A road thus fastened has never been known to spread, even a derailed vehicle cannot burst it. The plates also prevent rail cutting into sleeper on outside edge round curves." Sole-plates are sometimes used at joints. For further details I refer to the accompanying notes of a number of railroads.

### Joints.

The joints of English roads do not give so much trouble as those of American roads, and I think this is largely due to the security of the fastenings to the ties, especially the joint ties, and also to the wide spacing of the ties in the middle and close spacing at joints. Mr. Sand-

berg attributes this fact to the great weight of the rails. The joints are sometimes even and sometimes broken; sometimes supported, as on the Great Northern Railway, where two of the fish bolts pass through the jaw of a special joint-chair (Plate LXIII), but usually suspended. The ordinary joint consists of a pair of straight fish-plates, 18 inches long, with four bolts, the bolts having a square neck to prevent turning. The holes are generally spaced 4½ inches center to center; on the Lancashire and Yorkshire Railway the inner ones are 6 inches center to center, and the outer ones 4½ inches center to center, while on the Midland Great Western Railway (Ireland), the inner holes are 4 inches center to center, and the outer ones 5 inches center to center. On this line the rail-holes are 1-inch by 1¼ inches oval, one fish-plate has holes ¾-inch square and the other plate has them ¾-inch diameter. Generally the rail-holes are 1 by 1⅛ inches oval, and the fish-plate holes 1-inch square. The bolts are usually ⅞-inch diameter. Angle bars are used to some extent, also fish-plates with the lower part bent to nearly embrace half the lower head of double-headed rails. For flange rails, the Z plates, with a vertical web projecting below the flange of the rail, are frequently used, as shown on the drawing of the Great Southern and Western Railway (Ireland). A space of about $\frac{1}{16}$-inch is left between the ends of rails when laying track at ordinary temperature. Lock nuts are not much used.

### Cross-Ties.

The ties are usually of Baltic redwood, 10 by 5 inches by 9 feet, spaced 2 feet 9 inches to 3 feet center to center. They are almost invariably creosoted, with about 7 pounds of oil per cubic foot. Some roads have the creosoting done by contract; others have their own plant for the work. Among the latter may be mentioned the Lancashire and Yorkshire Railway and the Great Northern Railway (Ireland), both of which have very large and complete plants, and pay careful attention to the important point of tie preserving. (See Appendix B.) I will not now go further into this matter, as it has been dealt with in a paper by Mr. John Bogart, M. Am. Soc. C. E., entitled, "The Permanent Way of Railways in Great Britain and Ireland, with Especial Reference to the use of Timber Preserved and Unpreserved," and read November 20th, 1878.* I would say, however, that I do not think enough practical attention is paid in this country to the question of preserving railroad ties, and that some points in the matter may be learned from English practice.

Usually the ties are of rectangular section, but on the Midland Great Western Railway (Ireland), they are preferred of half-round section, except where the bearing plates are used. Mr. Price says that for heavy traffic he would prefer sleepers 11 by 5½ inches; he uses, however, sleep-

* Transactions, Vol. VIII, page 17, January, 1879.

ers 10 by 5 inches, 8 feet 11 inches long, always creosoted. The following is from the company's specifications: The timber is to be of good, sound Baltic red-wood, free from shakes or other defects, well seasoned and dry; 90 per cent. of both rectangular and half-round sleepers to have not less than 7½ inches diameter of heart wood; and 10 per cent. not less than 7 inches at both ends. On one side the rectangular sleepers to have 50 per cent. sharp edges down to 9 inches surface, and 50 per cent. not less than 8 inches; and on the other side all edges to be sharp. The rectangular sleepers to be grooved and bored and the half-round sleepers to be grooved, in accordance with templates, which will be supplied by the engineer. After being grooved and bored they are to be placed in a receiver and thoroughly impregnated with the best creosote oil (an equal mixture of light brown and black oil) under such pressure, and for such time, as shall entirely fill the pores with the liquid. The sleepers are not to be creosoted till they have been stacked in the contractor's premises for at least three months after inspection by the engineer. The engineer will reject, either before or after delivery, any sleepers which do not comply with the above conditions, or any sleepers the sap-wood of which has not been fully creosoted. Sections of these sleepers will be found on Plate LXVI.

Steel ties are in use on a large number of lines, and their use is being extended. They are of the "inverted trough" section, and are used mainly on divisions where there is a very heavy traffic. The bull-headed rail, with its heavy chairs, is, however, mounted on these ties, so that the entire metal track is very complicated and expensive, and represents a great amount of money sunk and absolutely wasted in metal, which with a proper form of rail would not be required at all. Each complete steel tie on the London and North Western Railway represents a considerable amount of shop work; the chairs being made of three plates rolled from the crop ends of steel rails, bent to the required shape and riveted to the tie; this work is done by the company at its own steel works at Crewe. With a well-designed flange rail of proper weight, a metal track could be obtained cheaper than the present expensive system, and fully as efficient.

The ballast consists generally of broken stone or furnace slag, on some lines covered with a boxing of gravel. On the Midland Railway the ballast has a flat outer slope and is brought up nearly level with the under side of the rail-head on the outside of the track, and level with the tops of the ties between the rails. The ballast is about 1 foot deep under the ties. Burnt clay is sometimes used.

### Switches and Crossings.

With double-headed rails the switches and crossings are very substantial, the rails being supported on each tie by specially cast chairs. The ties are generally 12 by 6 inches, spaced 2 feet 4 inches and 1 foot

10 inches at joints. The points of the switch-rails are housed under the heads of the stock-rails, and the chairs upon which the points of the switch-rails slide rest on a wrought-iron plate, which is nearly as long and broad as the face of the tie. The switch-rails are connected by tie rods. With a 12-foot switch-rail the switch-rail is 12 feet long and the stock-rail 19 feet 6 inches; with a 15-foot switch they are 15 and 22 feet long respectively, and with an 18-foot switch they are 18 and 30 feet long. A drawing of a three-throw switch shows a long switch-rail of 14 feet 6 inches, a short switch-rail of 12 feet and a stock-rail of 19 feet 6 inches. The throat of the frogs is usually ¾-inch wide, and a clearance of 2½ inches is given for wheel flanges. The heel joint of the switches is usually suspended. Cast crossings, whether of steel or iron, are in less favor than they were a few years ago; the ordinary built-up crossing finds most favor and is beginning to supplant the former in India and the colonies. With flange-rail tracks the rails are supported on chairs on each tie; and some of the obtuse crossings on the Great Southern and Western Railway (Ireland), are each supported on two iron plates about 1 foot wide by 2 feet 6 inches long, placed longitudinally and bridging across two ties, to which they are spiked.

The growth of switches and crossings can be traced from the oldest line in England, the Darlington section of the present North Eastern Railway system. Until about the year 1839, the switches on this line were made of cast-iron, with a wrought-iron movable tongue pivoted at the heel with a vertical pin; the usual length of this tongue was about 3 feet. The first switches made from rails were made at the blacksmith's fire, and were 6 feet long. The stub switch has never been adopted. Until about fifteen years ago the practice in the north of England was to notch the stock-rail to receive the switch tongue (See "*A*," on Plate LXVI); long before this, however, the Southern lines had adopted Wild's patent switch, which was introduced about the year 1844. In this switch the stock-rail was left intact and the web of the rail was let in under the head of the stock-rail at the point. Stock-rails are now very rarely notched, except in the flanges of Vignoles rail switches, but the points are rarely let in as far as with the original Wild's patent (See "*B*," Plate LXVI); "*C*" represents a very common practice; "*D*" represents the practice of the North Eastern Railway, in which the switch rail is planed off straight and laid against the stock-rail, the point being topped down so that the flange of the wheel passes over it. Until recently, the London and North Western Railway used the cranked stock-rail, but it is now abandoning it; this, as will be seen by the sketch "*E*" on Plate LXVI, served the same purpose as a notch. The joint at the heel is usually suspended, and the heel chair is dispensed with, the switch-rail, as well as the rail which joins on to the heel, being buttressed by three or four special chairs, one in front of the heel and the others behind. A set of switch chairs for a 15-foot switch on the Caledonian Railway weighs

1 036 pounds; a set of seven crossing chairs for a 1 in 10 crossing, 529 pounds, and the ten check chairs for two 15-foot check rails weigh 700 pounds. Most railways prefer to rivet the splice rail of a crossing to the nose rail, instead of bolting it; the best practice is not to notch the latter, although some railways prefer this plan. On some railways it is the practice to make the crossing so that the nose rail is always on the main line, the splice rail turning into the siding; this, of course, requires the crossing to be made both right and left. (Plates LXV and LXVI). (I am indebted to Mr. Thomas Summerson, of Darlington, a manufacturer of railway plant, for much of the above information respecting switches and crossings).

The following list of the weights of some English locomotives may be interesting in connection with the subject of the track of the railroads:

| | Weight in Gross Tons. | |
|---|---|---|
| | On driving axle. | Total. |
| Mersey Railway— | | |
| (*a*). Tank engine, 6 drivers, trailing truck..... | 17½ | 67¼ |
| Lancashire and Yorkshire Railway — | | |
| (*b*). Express; 4-coupled, leading truck..... | 14¾ | 41¾ |
| Great Western Railway— | | |
| (*c*). Express; 2 drivers, 4 leaders, single trailers... | 16 | 49 |
| Great Northern Railway— | | |
| (*d*). Express; 2 drivers, leading truck, single trailers. | 17 | 45½ |
| North Eastern Railway— | | |
| (*e*). Express, compound; 4-coupled, 1 leading axle. | 18 | 43⅗ |
| Midland Railway— | | |
| (*f*). Express; 4-coupled, leading truck..... | 15 | 42¼ |
| London and North Western Railway— | | |
| (*g*). Express, compound; 4 drivers, 1 leading axle. | 15 | 42½ |
| Caledonian Railway— | | |
| (*h*). Express; 2 drivers, leading truck, single trailers. | 17 | 42 |
| Great Southern and Western Railway (Ireland)— | | |
| (*i*). Express; 4-coupled, leading truck..... | | 39½ |
| North Eastern Railway— | | |
| (*j*). Freight; compound, 6-coupled ..... | 15½ | 41¼ |

(*a*) Cylinders, 21 by 26 inches; driving wheels, 4 feet 7 inches diameter; truck wheels, 3 feet diameter; weight on leading coupled wheels, 16¼ tons; on driving wheels, 17½ tons; on trailing coupled wheels, 17¼ tons; on trailing truck, 16¼ tons; total, 67¼ tons. The tanks are at each side of the boiler, built on the frames.

(*b*) Cylinders, 17½ by 26 inches; driving wheels, 6 feet diameter; truck wheels, 3 feet 7⅜ inches diameter; wheel-base of truck, 5 feet 6 inches; of driving wheels, 8 feet 7 inches; total, 21 feet ½-inch. Weight

on truck, 12⅖ tons; on drivers, 14¾ tons; on trailers, 14⅕ tons; total, 41¾ tons.

(*c*) Cylinders, 18 by 24 inches; driving wheels, 8 feet diameter; leading and trailing wheels, 4 feet 6 inches diameter. This is a broad (7 feet) gauge engine; similar engines for standard gauge have one pair of leading wheels, and driving wheels 7 feet diameter.

(*d*) Cylinders, 18 by 26 inches; driving wheels, 8 feet diameter; truck wheels, 3 feet 11 inches; trailing wheels, 4 feet 7½ inches; weight on truck, 8 1/10 tons on front axle and 9½ tons on rear axle; on driving wheels, 17 tons; on trailing wheels, 10⅗ tons; total, 45½ tons; tender on six wheels, 4 feet 1½ inches diameter.

(*e*) Cylinders, one high pressure, 18 by 24 inches; one low pressure, 26 by 24 inches; driving wheels, 6 feet 8½ inches diameter; leading wheels, 4 feet 7¼ inches; driving wheel-base, 7 feet 9 inches; total wheel-base, 16 feet 5 inches; weight on leading wheels, 12 7/10 tons; on driving wheels, 18 tons; on trailing wheels, 12½ tons; total, 43⅗ tons. Tender on six wheels, 3 feet 9½ inches diameter; wheel-base, 12 feet 8 inches; weight, 33 tons.

(*f*) Cylinders, 19 by 26 inches; driving wheels, 7 feet diameter; truck wheels, 3 feet 6 inches; driving wheel-base, 8 feet 6 inches; truck wheel-base, 6 feet; total wheel-base, 24 feet 6 inches; weight on truck, 14¾ tons; on driving wheels, 15 tons; on trailing wheels, 13 tons; total, 42¾ tons; weight of tender, 35 tons.

(*g*) Cylinders, two high pressure, 14 by 24 inches, driving the trailing driving wheels; one low pressure, 30 by 24 inches, driving the forward driving wheels; driving wheels, 6 feet 3 inches diameter; leading wheels, 3 feet 9 inches diameter; driving wheel-base, 9 feet 8 inches; total wheel-base, 18 feet 1 inch; weight on leading wheels, 12½ tons; on low pressure driving wheels, 15 tons; on high pressure driving wheels, 15 tons; total, 42½ tons.

(*h*) Cylinders, 18 by 26 inches; driving wheels, 7 feet diameter; truck wheels, 3 feet 6 inches; trailing wheels, 4 feet 6 inches; driving wheel-base, 8 feet; truck wheel-base, 6 feet 6 inches; total wheel-base, 21 feet 1 inch; weight on truck, 13½ tons; on driving wheels, 17 tons; on trailing wheels, 11½ tons; total, 42 tons; tender on six wheels, 4 feet diameter; wheel-base, 13 feet; weight, 33½ tons.

(*i*) Cylinders, 18 by 24 inches; driving wheels, 6 feet 6 inches diameter; truck wheels, 3 feet diameter; driving wheel-base, 8 feet 3 inches; truck wheel-base, 5 feet 3 inches; total wheel-base, 20 feet 5 inches.

(*j*) Cylinders, one high pressure, 18 by 24 inches; one low pressure, 26 by 24 inches; wheels (all coupled drivers), 5 feet 1¼ inches diameter; wheel-base, 16 feet 6 inches; weight on leaders, 14⅛ tons; on drivers, 15½ tons; on trailers, 12⅛ tons; total, 41¾ tons. Tender similar to that of engine (*e*).

While the American type of track, as a type, is probably the best that could be designed, yet there are many matters of detail in which it is open to improvement, and in some of these matters something may be learned from European practice. I now come to the description in detail of the tracks of some English railroads, but in concluding this first part of my paper I may say that I should very much like to see heavy rails on steel ties adopted for roads with heavy traffic. Of course, this is principally a question of expense, but in my opinion the metal ties should be adopted not only as a substitute for wood where, or when, timber is scarce, but as ordinary ties, for standard first-class track. In almost every large country but America, and in not a few of the smaller countries, metal sleepers have been given an extended trial, and in many cases they have passed beyond the experimental stage and are being introduced and extended very rapidly. It seems to me a pity that more is not done by American railroad engineers to try for themselves the advantages of metal track before the state of the timber supply, and the consequent excessive cost for wooden ties, compels them to take some action in the matter, for which they are not prepared.

### Great Northern Railway.

The standard track of this railway consists of Bessemer steel rails, of bull-headed section, 30 feet long, weighing 82 pounds per yard. They are supported in cast-iron chairs on each tie, the chairs having a base of 6¼ inches by 15½ inches, and weighing 40 pounds each; the joint chairs have a base of 8 by 15½ inches, and weigh 53 pounds each. The rails have an inward tilt of 1 in 24, given by the inclination of the seat in the chair. The ties are of Baltic redwood, creosoted with not less than 35 gallons of creosote forced into a load of 50 cubic feet of timber. They are 10 by 5 inches by 8 feet 11 inches, spaced 1 foot 9¼ inches, center to center, at joints, and 2 feet 7¼ inches, center to center, intermediate. The creosoting is done by contract; the contractor provides the plant and the company finds the ground. The life of the sleepers varies, of course, but the average may be taken as about ten years. The rails are secured in the chairs by compressed fir keys driven between the web of the rail and the jaw of the chair, on the outside of the track. The ordinary chairs are attached to the ties by two trenails and one round spike; the joint chairs by two trenails and two spikes. The trenails are of English oak, and are compressed not less than $\frac{7}{16}$-inch; the keys are compressed not less than ⅜-inch. The rail joints are even and are spliced with two plain, straight fish-plates, 18 inches long by 2$\frac{13}{16}$ inches deep and 1-inch thick, with four ¾-inch bolts, and there is a space of ¼-inch between the plate and the web of the rail; the plates weigh 20 pounds per pair. The two outer bolts pass through the rail and fish-plates as in the ordinary joint, but the two bolts next the rail ends also pass through the jaw of the chair, which is on the out-

side of the track. The holes in the plates are 1-inch square, spaced 4½ inches, center to center. The switches and crossings are made from steel rails. (Plate LXIII).

(An estimate of the cost of laying one mile of single track road is given in Appendix "A," the prices being those of 1885).

### North Eastern Railway.

The standard track of this railway consists of steel rails, of double-headed (reversible) section, 30 feet long, weighing 82 pounds per yard. They are supported in cast-iron chairs on each tie, the chairs having a base of 7¾ by 12½ inches, and weighing 40 pounds each. The rails have an inward cant of 1 in 20. The ties are 10 by 5 inches by 9 feet, and there are eleven ties to each rail, spaced as follows: 2 feet 3¼ inches, center to center at joint; 2 feet 4 inches; 2 feet 8 inches; 2 feet 10 inches; 3 feet; 3 feet ½-inch; 3 feet ½-inch; 3 feet; 2 feet 10 inches; 2 feet 8 inches; 2 feet 4 inches; and 2 feet 3¼ inches at the joint. The rails rest on wooden cushions in the seat of the chairs, and are secured by wood keys driven on the outside of the track. Each chair is attached to the tie by four 22-ounce spikes. The rail-joints are even and suspended; they are spliced by a pair of plain fish-plates and four bolts; the fish-plates weigh 13 pounds each, and a bolt and nut 24 ounces. The bolt holes in the rail are 1 by 1⅛ inch, oval. A space of ¼-inch is left between the rail ends at the joints. (Plate LX).

(An estimate of cost per mile is given in Appendix "A," the prices being those of 1887).

### Lancashire and Yorkshire Railway.

The standard track of this railway consists of steel rails, of bull-headed section, 30 feet long, weighing 86 pounds per yard. The sectional dimensions are: height, 5 5/16 inches; width of head and base, 2 3/16 inches; thickness of web, 3/8-inch, sectional area, 8.52 square inches. They are supported in cast-iron chairs on each tie; the chairs having a base of 7¾ by 15½ inches, having a base area of 120 square inches, and weighing 56 pounds each. The rails have an inward cant of 1 in 20. The ties are 9 feet by 10 by 5 inches, spaced 2 feet 9½ inches and 2 feet 10½ inches, center to center, and 2 feet at joints; they are of creosoted Baltic timber and weigh 158 pounds each. Their average life is about sixteen years. The rails are secured by keys of compressed yellow pine, coated with black lead, on the outside of the track; these keys are 6½ inches long and 2⅞ inches deep, tapered lengthwise from 2 to 1⅝ inches in thickness, and weighing about ½ pound each. Each chair is attached to the tie by two spikes and two trenails, the latter blackleaded. The spikes are of wrought-iron, 6¼ inches long from the underside of the head, 13/16-inch diameter, and weighing 1½ pounds each. The trenails are of American oak, compressed and blackleaded; they are 6 inches

long, tapering for about one-third of their length, from the head, from $1\frac{1}{2}$ inches diameter to $1\frac{1}{8}$ inches, and the remainder from $1\frac{1}{8}$ to $1\frac{1}{16}$ inches; they weigh about 4 ounces each. The joints are even and suspended; they are spliced by plain, straight fish-plates, fastened by four steel bolts, with the Ibbotson steel lock nut. The plates are of steel, 18 inches long, $3\frac{3}{4}$ inches deep on the outside and beveled to $2\frac{3}{16}$ inches on the inside; they are $\frac{5}{8}$-inch thick, and weigh 28 pounds per pair. They are so shaped as to bear only on the underside of the head and the top of the base of the rail, leaving a clear space of about $\frac{1}{4}$-inch between the plate and the web of the rail. One of each pair of plates has square punched holes to fit the square neck of the bolts, the other has round holes; the former are 1-inch square and the latter 1-inch diameter; the holes in the rails are $1\frac{1}{4}$ by $1\frac{1}{8}$ inches, oval. The inner holes are 6 inches center to center, the outer ones $4\frac{1}{8}$ inches. The bolts are $4\frac{1}{4}$ inches long from the under side of the head, $\frac{7}{8}$-inch diameter, square necked for about $\frac{3}{4}$-inch from the head, and weigh, with washers, $1\frac{1}{4}$ pounds each. A space of $\frac{1}{4}$-inch is left between the ends of the rails at joints.

Flange rails have been abandoned, except at engine pits, etc., but this flange-rail track (which is shown on the drawings) presents some interesting points. The rails are of steel, 21 feet long, weighing 72 pounds per yard. The sectional dimensions are: height, $5\frac{7}{32}$ inches; width of head, $2\frac{7}{32}$ inches; width of base, 5 inches; thickness of web, $\frac{7}{32}$-inch. They are carried on longitudinal timbers, to which they are secured by "bracket chairs," which consist practically of a pair of short angle-bars, 6 inches long, $\frac{1}{2}$-inch thick, and weighing $5\frac{1}{2}$ pounds each, bolted together through the rail with one $\frac{7}{8}$-inch wrought-iron bolt, $4\frac{1}{4}$ inches long, weighing $1\frac{1}{4}$ pounds. Each pair of plates is fastened to the sleeper by one spike and one coach-screw, passing through the horizontal flange and arranged alternately on the inside and outside of the rail. The spikes are of wrought-iron, $\frac{11}{16}$-inch diameter, $4\frac{1}{4}$ inches long under the head, weighing $10\frac{1}{4}$ ounces each; the coach-screws are $\frac{3}{4}$-inch diameter, $5\frac{1}{2}$ inches long under the head, weighing, with washers, $14\frac{1}{4}$ ounces each. The "brackets" are spaced 3 feet $1\frac{1}{2}$ inches center to center, and 2 feet 3 inches, center to center, at joints. The joints are spliced with straight wrought-iron plates, 18 inches long, $\frac{15}{16}$-inch thick, weighing 22 pounds per pair; they are bolted together by four wrought-iron bolts, $\frac{7}{8}$-inch diameter, $4\frac{1}{4}$ inches long, weighing $1\frac{1}{4}$ pounds each. The mode of attachment would seem to be unnecessarily expensive for the class of track for which it is used, but would make a very safe track for ordinary traffic.

The frogs are made of bull-headed rails, planed and spliced, with cast-iron collars or coupling chairs, each cast to the proper angle and generally embracing the wing or guard rail as well. The ballast consists of a layer of hard rough stone pitching, 9 inches deep, laid on

edge and hand-packed as closely and compactly as possible: over this is spread a layer of ashes 9 inches thick, on the top of which the sleepers are laid and packed throughout until an even surface is obtained, after which the line is boxed to the level of the underside of the rail. This company has its own plant for seating, boring and creosoting its ties, and has also a machine for attaching the chairs to the ties in the shop, thus saving work on the track. (Plate LXI).

(An estimate of cost per mile, etc., is given in Appendix "A," the prices being those of 1887. A description of the creosoting plant and process is given in Appendix "B").

### Midland Railway.

The standard track of this railway consists of steel rails, of bull-headed section, 30 feet long, weighing 85 pounds per yard. They are supported in cast-iron chairs on each tie, the chairs having a base of 15½ by 7½ inches and weighing 50 pounds each; the edges of all chairs are rounded to prevent chipping. The rails have an inward tilt of 1 in 22. The ties are laid with the sawn face up and are spaced as follows: 2 feet 2 inches at joint; 2 feet 3 inches; 2 feet 9 inches; 2 feet 11 inches; 3 feet; 3 feet; 3 feet; 3 feet; 2 feet 11 inches; 2 feet 9 inches; 2 feet 3 inches, and 2 feet 2 inches at the joint. The rails are secured in the chairs by oak keys 7 inches long and about 2½ inches by 3¾ inches section. Instead of nails being used to prevent keys from dropping out, the ballast is required to be banked up level with the top of the keys. The keys are on the outside of the track. The chairs are attached to the ties by two spikes and two oak trenails. The joints are even and suspended; they are spliced by a pair of deep fish-plates, the lower part being curved to embrace the lower head, so that the bottom edges of the plates nearly meet under the rail. (Plate LXII). The plates are 18 inches long, weigh 40 pounds per pair and are fastened by four ⅝-inch steel bolts. The bolt holes in the rails are 1 inch by 1¼ inch, oval, and the holes in the fish-plates are 1-inch square; they are spaced 4½ inches, center to center. A space of $\frac{3}{16}$-inch is left between the rail ends at ordinary temperature. The frogs are made of steel rails; for all common crossings a check rail is placed on each side, at least 12 feet in length, and much longer in special cases. The narrowest part of the throat of the frog is 1¾ inches wide. At switches the ties are 12 by 6 inches or 10 by 5 inches, of suitable length, and spaced about 2 feet 2 inches, center to center. The switch-rails are connected by 1¼-inch tie rods, and are cut down near the ends so that the tongue is housed under the head of the stock rail. The ends of wing rails at frogs are turned out with a radius of 18 inches. Wooden blocks are fitted in the "V" part of common crossings in some cases, to prevent coupling chains from catching. (Plate LXII).

### Great Eastern Railway.

The standard track of this railway consists of steel rails, of bull-headed section, 30 feet long, weighing 80 and 85 pounds per yard; the 80-pound rails have a rounded head, while the 85-pound rails have vertical sides to the head. They are supported in cast-iron chairs on each tie, the chairs having a base of $6\frac{3}{4}$ by $15\frac{1}{4}$ inches, and weighing 43 pounds each. The rails have an inward tilt of 1 in 22. The ties are 9 feet by 10 inches by 5 inches; spaced from 2 feet 1 inch at the joints to 2 feet $9\frac{1}{2}$ inches at the middle. The rails are secured by oak keys, driven on the outside of the track. The chairs are attached to the ties by two $\frac{5}{8}$-inch spikes and two $\frac{1}{4}$-inch oak trenails. The joints are suspended and are spliced by deep fish-plates, similar to those of the Midland Railway; they are 18 inches long and weigh 34 pounds per pair. The bolt holes in the rails are $1\frac{5}{16}$-inch by $1\frac{1}{8}$ inches, oval; the holes in the fish-plates are $1\frac{3}{16}$-inch square; the bolts being $\frac{3}{4}$-inch diameter. The inner holes are spaced $5\frac{3}{4}$ inches, center to center, and the outer ones $4\frac{1}{2}$ inches. No frog is to be laid at a flatter angle than 1 in 8, and as far as possible to be limited to 1 in 6. All frogs to be laid tight to gauge, from 4 feet 8 inches to 4 feet $8\frac{1}{2}$ inches, as circumstances may require, and each line to cross on the straight, wherever possible, for at least 20 feet on each side of the crossing. All frogs to give a depth of not less than $2\frac{1}{2}$ inches clearance for the flanges of wheels. The ballast is of gravel and is 1 foot deep under the ties. (Plates LXIII and LXV).

### Severn and Wye and Severn Bridge Railway.

This road was originally laid with flange rails, but double-headed rails have now been adopted on the main portions of the line, because, to quote the words of the engineer: "We found that the flange, or Vignoles, rail was troublesome and expensive to maintain and keep in order on a line where the gradients are steep, curves sharp, and on which tank engines weighing, loaded, nearly 50 tons, are employed." A peculiarity of the flange-rail track of this road is that the rails are supported in heavy cast-iron chairs having one jaw. (Plate LXIV). Two $\frac{3}{4}$-inch fang bolts pass through each chair, the nuts and washers being on the under side of the tie and the bolts being screwed up from the top. The inside bolt has a clip washer, which holds the flange of the rail, the outside flange being held by the jaw of the chair. The rail weighs 72 pounds per yard and is $4\frac{7}{8}$ inches high, with a flange $4\frac{1}{4}$ inches wide. The chairs have a base of about $5\frac{1}{2}$ inches by $10\frac{1}{2}$ inches. The main objects of the chair are, of course, to distribute the load, to prevent the rail from cutting the tie, and to keep the track from spreading at curves. These are very desirable and important points, but a well-designed shoe or sole-plate would be probably as efficient and certainly cheaper. On curves even, such a form of chair would seem to be hardly necessary, except

in special cases or under very heavy, rapid or constant traffic. The joints are spliced with fish-plates weighing 20 pounds per pair, fastened with four $\frac{7}{8}$-inch bolts. The flange rails are of steel, 21 feet long, 72 pounds per yard, carried on Baltic timber creosoted ties, 10 by 5 inches by 9 feet, spaced about 2 feet 8 inches, center to center. The double-headed rails are of steel, 29 feet long, 80 pounds per yard, carried in cast-iron chairs, which weigh 38 pounds each and are fastened to the ties by two fang bolts. The wooden keys are on the inside of the track. The ties are spaced 3 feet, center to center, but closer at joints. The ballast is chiefly furnace slag. The width at formation level (sub-grade) is 16 feet. The working load on grades of 1 in 30 is 70 tons, for freight engines with 16-inch cylinders; on grades of 1 in 40 to 1 in 50 it is about 100 tons or 120 tons. The switches on the flange-rail sections of the track have the stock rails cranked to let in the tongue of the switch-rail, the flanges of the rails being cut away to let the heads come together. The curves on these sections of track range from 462 feet and 528 feet to 2 970 feet, with a great number of about 600 and 800 feet. On the sections laid with double-headed rails the curves range from 660 feet to 1 980 feet.

On the Severn Bridge, which is owned by this company, the track consists of bridge rails (Plate LXIV), 24 feet long, weighing 68 pounds per yard, laid on longitudinal sleepers. The rails are secured to the sleepers by four fang bolts at the joints, two fang bolts at the middle and coach-screws at intermediate points. Sole-plates are used at the rail joints. There is an angle iron guard rail, $4\frac{1}{2}$ by $4\frac{1}{2}$ inches, fastened to the sleepers by fang bolts and tied to the track rail by iron sole-plates. The longitudinal timbers are of creosoted yellow pine, 14 by 7 inches, connected by transoms and tie rods at intervals of 11 feet. (This track is very similar to Brunel's original type of track for the Great Western Railway, which is still in use on the 7-foot gauge portions of that line.)

### Great Northern Railway (Ireland).

On this line (Irish gauge—5 feet 3 inches), both bull-headed and flange rails are used, the former being considered the best for sections with heavy grades and sharp curves. The bull-headed steel rails weigh 75 pounds per yard and are supported in cast-iron chairs weighing $36\frac{1}{2}$ pounds each, being secured by wooden keys, which are driven on the inside of the track. The chairs are fastened to the ties by three spikes, $\frac{3}{4}$-inch diameter. The joints are spliced with deep bent fish-plates, somewhat similar to those of the Midland Railway, except that the bottom ends of the plates do not nearly meet under the rail, a space of $1\frac{1}{2}$ inches intervening. The plates are of steel, 18 inches long and are fastened by four bolts. The rail-head has a top table of 10 inches radius, semicircular top corners of $\frac{1}{2}$-inch radius, a vertical portion $\frac{7}{16}$-inch deep, and bottom corners of $\frac{3}{8}$-inch radius. The flange rails are of steel,

21 feet long, and weigh 79 pounds per yard; they are 4⅝-inches high, with a base of 5 inches, and a head of similar shape to that of the bull-headed rails. At the joint ties the rails are secured by one ¾-inch fang-bolt and one jagged spike, the former passing through the flange of the rail; at the middle tie each rail is fastened by two fang-bolts, which grip the flange by means of clips or washers; these washers have a sharp projecting rib at one end, which cuts into the wood of the tie when the bolt is screwed up. The bolts have square heads ⅝-inch deep, 1½ inches square at the top and 1 1/16 inches at the bottom. At intermediate ties each rail is fastened by two jagged spikes. The joints are spliced with one straight plate and one Z-plate (Plate LXIII), the latter being on the outside of the track. The plates are of steel, 18 inches long, and the nuts of the fish-bolts are on the inside of the track. Both forms of rail are laid with an inward inclination of 1 in 20; this being secured in the chair seat for the bull-headed rails and by adzing out a seat in the tie for the flange rails. When relaying, ⅜-inch is allowed for expansion at rail joints. The switches are made out of steel rails, planed down to form the switch rail, which slides on cast-iron chairs firmly bolted to the stock rail. Cast-steel reversible block crossings (frogs) are used. The joints are even and suspended. The ties are rectangular, 10 by 5 inches, and 8 feet 11 inches long; they are spaced 2 feet 4 inches at joints, 2 feet 10 inches next to the joints, and 3 feet intermediate. They are of creosoted Baltic timber, and cost, when sawn, grooved and creosoted, 88 cents each. This company pays particular attention to its ties, and has a complete plant for sawing, cutting the rail seats, and creosoting. (Plates LXIII and LXIV).

(For particulars of the creosoting plant and process, see Appendix "B").

### West Riding and Grimsby Railway.

The original track of this line was a good example of a heavy flange-rail track. (Plate LXIV). It consisted of flange rails 24 feet long, weighing 83 pounds per yard, carried on ties 10 by 5 inches, by 8 feet 6 inches, spaced 1 foot 10 inches at joints and 2 feet 9½ inches intermediate. The inward inclination of 1 in 20 was given to the rails by cutting an inclined seat in the tie, which seems to be an objectionable feature, tending to cause the flange of the rail to cut into the tie, though this may have been neutralized to some extent by the wide base of the rail, 6 inches. The joints were suspended and were spliced by straight fish-plates 15 inches long, weighing 24 pounds per pair, with four ¾-inch bolts, the nuts of which were on the inside of the track: the bolts were spaced 4 inches, center to center, and weighed 5.2 pounds per set of four. Each rail was fastened to the joint ties by two ¾-inch fang-bolts, passing through a ¾-inch hole in the flange, the fang nut being at the under side of the tie and the head of the bolt bearing on a washer on the rail

flange. The intermediate fastenings consisted, I believe, of spikes and fang-bolts, all passing through the flange, a practice which is costly and objectionable in other ways. The road, however, was acquired by the Great Northern Railway and the track was taken up and the line relaid with the Great Northern standard track, previously described, entailing what would seem to have been an enormous and unnecessary expense, the new track costing about $8 000 per mile, with rails at $25 per ton. A comparative estimate of the cost of construction for this flange-rail track and the old track of the London and North Western Railway, with an 84-pound double-headed rail in chairs, shows $8 641 per mile for the former, and $10 476 for the latter, a difference of $1 835 per mile in favor of the flange rail; these prices are from old estimates and are not reliable for the cost of modern track, but as they are both for about the same date they will suffice for comparison.

### Great Western Railway.

On this line there are used bridge rails, bull-headed rails and flange rails. The former are on the 7-foot gauge portions of the line, and are secured by screws and fang-bolts to longitudinal timbers. This gauge, rail and form of track was designed by Mr. Brunel, and the riding over this track at express speed is wonderfully easy and steady. The rails are quite light, 68 pounds per yard, 6½ inches base, 3 inches high. The timbers are of creosoted pine, 15 inches wide, 7½ inches deep on the outer side and 7 inches on the inner side, thus giving the rails an inward inclination. At intervals of 11 feet there are transverse timbers, about 6 inches square, notched into the longitudinals and fastened to them by iron angle-braces or knees. The clear distance between the inner rails on double track is 6 feet 4 inches, and the inner longitudinals of each track are connected at intervals of about 14 feet by cross-pieces about 6 inches square. A strip of tarred felt is laid under the whole length of the rails. The broad-gauge portions have now a third rail for standard gauge, and new lines are laid to standard gauge with bull-headed rails weighing 86 pounds per yard, carried in cast-iron chairs weighing 46 pounds each. Double-headed rails are not used, as they cause the trains to ride roughly if reversed, in consequence of the indentations made by the chairs. The joints are even and suspended. Flange rails and chairs are secured to the ties by fang-bolts $\frac{7}{8}$-inch in diameter; each chair has two fang-bolts. The wooden keys are placed on the outside of the track. The fish-plates for the bull-headed rails are 20 inches long and 3¼ inches deep, with holes 5 inches center to center. The holes are of peculiar shape, being about three-fourths of a circle and then tapering off in a triangular form, making a somewhat kite-shaped hole with the narrow part pointing outward to the end of the plate. This narrow part receives a projection on the neck of the $\frac{7}{8}$ inch bolt, in order to prevent turning; the rail-holes are circular. The fang-nuts are 3½ inches

square. A space of $\frac{1}{8}$-inch is left between rail ends at joints. The ties are of creosoted pine, 9 feet long, 10 inches by 5 inches; they cost 78 cents each, including creosoting. They are spaced about 2 feet 8¼ inches. The ballast used is gravel, cinders, stone, slag, etc. The maximum grade on the system is 1 in 30, and the curves range from 330 feet to two miles radius. The bull-headed rail is now the standard for this line. (Plate LXIII).

### Great Southern and Western Railway (Ireland).

On this line, flange rails, weighing 74 pounds per yard, are used, but the bull-headed rail is considered the best where traffic is heavy. The joints are even and suspended, spliced with angular (Z) fish-plates, 18 inches long, weighing 14.74 pounds each, and having four square holes. The fish bolts have square necks, and weigh 17½ ounces each. Plain straight fish-plates are also used. The rail holes are 1 inch by 1¼ inches, oval; the middle ones are spaced 6 inches and the outer ones 4 inches, center to center. The rails are 30 feet long, and are carried on eleven ties of Baltic redwood, 9 feet long by 10 inches by 5 inches, creosoted with an average of 3.39 gallons of oil each. The life of the ties averages fifteen to twenty years. The ballast is of gravel, 2 feet deep from the top of the rail, and covers the ties. The gauge is 5 feet 3 inches; 6 feet between tracks; width at sub-grade 28 feet in cutting and 32 feet in bank. The sharpest curve is 1,000 feet radius, and the steepest grade 1 in 60. (Plate LXIV).

### Midland Great Western Railway (Ireland).

This line is laid with flange rails weighing 79 pounds per yard, the specifications and tests for which have been already given. The joints are spliced with L fish-plates, weighing 14 pounds, having a narrow horizontal flange at the bottom. The ties are preferred spaced 3 feet 6 inches, center to center, this being considered better than 3 feet; at joints they are spaced 2 feet. The rail is of unsightly appearance, and has an unnecessary amount of metal at the base of the web. The joints are even and suspended. At the joint and middle ties the rails rest on sole-plates 8½ inches by 6 inches; the channel part for the rail is $5\frac{1}{16}$ inches wide, this part is $\frac{3}{8}$-inch thick, while the sides are $\frac{1}{4}$-inch thick; in each side is a $1\frac{3}{8}$-inch hole for the fang-bolt. The head of the bolt has a washer which grips the rail flange, and the nuts of the two bolts in each tie are held in a single "channel washer," on the underside of the tie. (Plate LXIII). This washer is 10½ inches long, 3 inches wide, channel $2\frac{1}{8}$ inches wide; it is $\frac{1}{4}$-inch thick, with flanges $\frac{1}{4}$-inch deep; the holes are $1\frac{1}{4}$-inch by $1\frac{3}{4}$-inch. The ballast consists of mixed gravel and coal ash for bogs. The steepest grade is 1 in 65; maximum grade for new lines, 1 in 100. The sharpest curve on the line is ¼-mile radius; the sharpest

in yards is $\frac{1}{3}$-mile. The heaviest tank engine is 44 tons, with 15 tons on driving wheels; the heaviest ordinary engine is 57½ tons, with tender weighing 13 tons. The switches and frogs are made of steel rails, and the quantities of material are as follows:

Switch.

No. 2. Rails, 26 feet 6 inches long.
" 2. " 13 " 3 " "
"12. Wrought-iron slide chairs.
" 2. Cast-iron heel blocks.
" 2. Connecting rods.
" 1. Pulling rod and pins (turned).
"12. Slide chair, $\frac{7}{8}$-inch bolts and nuts.
" 8. $\frac{7}{8}$-inch heel bolts.
"24. $\frac{3}{4}$ " fang-bolts.
"36. $\frac{5}{8}$ " rivets.
" 2. Fish-plates.
(All to receive one coat of red lead.)

Frog.

No. 2. Point rails, 9 feet 9 inches long.
" 1. Wing rail, 16 feet long.
" 1. Wing rail, 11 feet 6 inches long.
" 5. Crossing plates.
" 9. Cast-iron chogs.
" 8. Crossing body bolts, $\frac{7}{8}$i nch.
" 10. Wrought-iron clips (planed and drilled).
" 10. Fang-bolts, 9 by $1\frac{1}{16}$ inches.
" 34. $\frac{5}{8}$-inch rivets.
(All to receive one coat of red lead.)

Isle of Wight Railway.

On this line double-headed steel rails are used, weighing 75 and 78 pounds per yard, the latter being now adopted as standard; the head is $2\frac{3}{8}$ inches wide and the web $\frac{5}{8}$-inch thick. Although reversible, the rails are not turned over, experience showing that they are rough to travel over and more liable to break. With the light traffic on this line the 78-pound rails will last from fifteen to twenty years, according to their position in the track. The rails are 24 feet long. The chairs are of cast-iron, weighing 35½ pounds each, and are fastened to the ties by two hollow trenails, an iron spike being driven into the trenail when the latter is in place. The joints are suspended and are spliced by straight steel fish-plates, 18 inches long, 3 inches deep, $\frac{3}{4}$-inch thick in the web, and thicker at top and bottom; they weigh about 23 pounds per pair; the fish-bolts are $\frac{3}{4}$-inch in diameter and weigh 1.28 pounds each.

normal temperature (60 degrees) a space of ⅛-inch is left for expansion at the joints. The old 70-pound flange rails were fastened to the ties by ⅝-inch fang-bolts, one inside and one outside, alternately, with large triangular fang nuts under the tie. The ties are of Baltic timber, 9 feet by 10 by 5 inches, spaced 2 feet 4 inches at joints and 2 feet 8½ inches intermediate, nine ties to a rail. They are creosoted with 7 pounds of fluid per cubic foot of timber and cost 84 cents each. Their average life is fifteen years in the main line and a few years more in side tracks. The ballast is of chalk and gravel, obtained on the island, laid 12 to 18 inches deep and 12 feet wide. The switches and crossings are made of steel rails; the switch rails are 12 feet long, well cut away at the points so as to be housed under the head of the stock rail for about 6 inches. The steepest grade is 1 in 70 for about two miles; there are numerous curves, a few of 792 feet radius. The traffic is principally passenger, and there are twelve to fourteen passenger trains each way per day and one freight train each way. Tank engines are used, with side tanks; the passenger engines weigh 25 tons, freight engines 28 tons; the driving and trailing wheels are 5 feet diameter (coupled), and the leading wheels 3 feet 6 inches diameter; the weight on the driving wheels is 12 to 13 tons. Mr. Conner, the former engineer, says he considers the road described "a good reliable track for the traffic, and over twenty years of experience has shown the superiority of double-headed rails with chairs, over flange or Vignoles rails, it being a firmer and stronger road, cheaper to maintain and easier to repair."

### Great North of Scotland Railway—Speyside Division.

The Speyside Railway is a single line, which was constructed in 1863. The track consists of iron rails, 21 feet long, weighing 65 pounds per yard, supported in cast-iron chairs weighing 20 pounds each, and joint chairs weighing 25 pounds each. The rails are secured in the chairs by keys, which are placed on the outside of the track; the keys in the ordinary chairs are of wood, those in the joint chairs are iron cotters. The joints are insistent, the rail ends resting in a joint chair; fish-plates are used. Each chair is fastened to the tie by two spikes. The ties are of Scotch fir, placed 3 feet apart. The ballast consists of broken stone and gravel.

The main line of the Great North of Scotland Railway is laid with double-headed steel rails, weighing 72 and 80 pounds per yard, but I mention this division as a specimen of a light track with double-headed rails. The description of the track is taken from a recent report by Major-General Hutchinson, of the Board of Trade, upon a slight accident which occurred to a mixed train. The accident was a derailment of the engine, caused by the breaking of a spring on the tender; the accident is attributed to a defective spring, but the report states that "very

probably the fracture of this spring would not have caused an accident if the engine had been running upon a better and stronger road." The road was not in good condition at the time. It is to be presumed that the track on this division will sooner or later be replaced with the standard track, but with a 75-pound steel flange rail, secured by bolts to the ties, and with a well-constructed track, the line would probably be of ample s rength for the traffic, costing less for material and no more for maintenance. At the time when a 65-pound rail was sufficient, the cast-iron for chairs was so much unnecessary metal in which money was sunk for no useful purpose and giving no return in efficiency.

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The illustrations accompanying this paper are:

Plate LX. Permanent Way, North Eastern Railway.
" LXI. Permanent Way, Lancashire and Yorkshire Railway.
" LXII. Permanent Way, Midland Railway.
" LXIII. Nine-rail Sections; Rail Joint of Great Northern Railway; Rail Joint of Midland Great Western Railway of Ireland; Crossing of Great Eastern Railway.
" LXIV. Permanent Way of Great Northern Railway of Ireland; of Severn and Wye and Severn Bridge Railway; of Great Southern and Western Railway of Ireland; of West Riding and Grimsby Railway.
" LXV. Switch of Great Eastern Railway.
" LXVI. Sections of Switch Rails. Sections of Timber Cross Ties of Midland Great Western Railway of Ireland.

## APPENDIX "A."

[Estimates of Cost.]

1.—Great Northern Railway—Estimate of Cost of One Mile of Single Track. Prices of 1885.

| | | | | |
|---|---|---|---|---|
| Rails | 129 | tons at | $25 00 | $3 225 00 |
| Chairs | 77 | " " | 17 50 | 1 347 50 |
| Plates | 3.3 | " " | 37 50 | 123 75 |
| Bolts | $\frac{938}{1000}$ | " " | 60 00 | 56 28 |
| Spikes | 3.77 | " " | 45 00 | 169 65 |
| Ties | No. 2 112 | " | 87½ | 1 848 00 |
| Keys | " 4 224 | " | 22 50 | 95 04 |
| Trenails | " 4 224 | " | 17 50 | 73 92 |
| Labor | 1 760 | " | 25 | 440 00 |
| | | | | $7 379 14 |
| Contingencies, 10 per cent | | | | 737 91 |
| | | | | $8 117 05 |

Note.—This does not include ballast; single line = 4 777 cubic yards at 63½ cents ..... $3 033 39

2.—North Eastern Railway—Estimate of Cost of One Mile of Single Track. Prices of 1887.

| | | | | |
|---|---|---|---|---|
| Rails | 129 | tons at | $22 50 | $2 902 50 |
| Chairs | 69 | " " | 12 50 | 862 50 |
| Spikes* | No. 11 616 | " | 18 75 | 217 80 |
| Fish-bolts and nuts | " 1 408 | " | 26 25 | 36 96 |
| Fish-plates | " 704 | " | 15 | 105 60 |
| Wood keys and cushions | " 7 744 | " | 12 50 | 58 08 |
| Ties, creosoted | " 1 936 | " | 70 | 1 355 20 |
| Labor of laying | 1 760 yards | " | 12½ | 220 00 |
| Ballast,† 13 feet wide 18 inches deep | 3 588 cubic yds. | " | 11 | 394 68 |
| Total | | | | $6 153 32 |

* Say 3 in each chair; but only two are often used.

† Coke ballast is obtained from the collieries in the immediate vicinity of the line, and is supplied and loaded up free by the colliery owners, as they are glad to get rid of it: 11 cents per cubic yard is an average charge intended to cover carriage, tipping and spreading.

3.—Lancashire and Yorkshire Railway—Estimate of Cost of One Mile of Single Track. Prices of 1887.

| | | | | | |
|---|---|---|---|---|---|
| Rails | 3 520 yards | 135.1 tons, at | $22 50 | | $3 039 75 |
| Chairs | 3 872 No. | 96.8 " " | 15 00 | | 1 452 00 |
| Fish-plates | 352 " | 2.2 " " | 27 50 | | 60 50 |
| Fish-bolts | 704 " | .6 " " | 80 00 | | 48 00 |
| Spikes | 7 754 " | 3.9 " " | 32 50 | | 126 75 |
| Ties | 1 936 " | " | 75 | | 1 452 00 |
| Trenails | 1 744 " | " | 17 50 | | 135 52 |
| Keys | 3 872 " | " | 19 50 | | 75 50 |
| Laying 1 760 yards | | " | 25 | | 440 00 |
| Total | | | | | $6 830 02 |

A later estimate, the prices of which are a little lower than the foregoing, gives the following details of prices per rail length, or 10 linear yards:

Material.

| | | |
|---|---|---|
| 11 Ties | | $5 92 |
| 22 Chairs | | 7 79 |
| 44 Spikes | | 32 |
| 44 Trenails | | 21 |
| 20 yards of rails | | 16 08 |
| 22 Keys | | 44 |
| 4 Fish-plates | | 63 |
| 8 Bolts | | 40 |
| 5 cubic yards top ballast for boxing up | | 90 |
| | | $32 69 |

Labor.

| | | |
|---|---|---|
| 10 linear yards laying | $1 70 | |
| 2 tons carriage | 96 | |
| 4 hours trucking and unloading | 52 | |
| | | $3 18 |
| | | $35 87 |

Or $3.58 per linear yard.

The weight of the track in pounds is as follows:

| | | For 10 yards. | For 1 yard. |
|---|---|---|---|
| Steel. | Rails, 1 760, Plates, 56, Bolts, 12, | 1 828 | 182.80 |
| Wrought-iron | | 49½ | 4.95 |
| Cast-iron | | 1 232 | 123.20 |
| Wood. | Ties, 1 738 Trenails, 11 Keys, 11 | 1 760 | 176.00 |
| | | 4 869½ | 486.95 |

## APPENDIX "B."

[Treatment of Railway Ties.]

### (1.)—Lancashire and Yorkshire Railway.

The ties, after being well seasoned, are passed through a combined adzing and boring machine, which first cuts out a seat, about $\frac{1}{16}$-inch deep, for the chairs, in order to give them a uniform bearing, and then simultaneously bores the eight holes required for chair fastenings in each tie. The machine will seat and bore about 100 ties per hour.

The ties are then placed on small iron trucks and drawn on a tramway of 3-foot gauge into the cylinder, which contains eight trucks with 47 ties each, or 376 ties in all. The cylinder is 77 feet long, 6 feet internal diameter, built of $\frac{1}{2}$-inch wrought-iron plates and having egg-shaped ends. When the full number of ties has been put in, the doors or covers are put on and hermetically fastened by means of dog-bolts and screws, and the air exhausted by a steam ejector. The creosote is then introduced, heated to a temperature of from 100 to 120 degrees Fahr.; the air pump then ceases to work and the pressure pump is put into operation, the full pressure of 150 pounds per square inch being obtained in about ten minutes; this pressure is maintained for about fifty minutes, and is then withdrawn. The spare creosote is allowed to run back into the reservoir under the cylinder, the cover is removed, and after the ties have been left to drip for about fifty minutes, they are taken out of the cylinder. About three gallons of creosote are allowed for each tie, or 9½ pounds per cubic foot of timber. The efficiency of the process is ascertained by weighing three or four ties out of every charge, both before and after the operation, the additional weight showing the quantity absorbed, which averages about 30 pounds per tie.

| | | |
|---|---|---|
| Average weight of tie before creosoting..... | 128 | pounds. |
| Gain in weight during process..... | 30 | " |
| Average weight of creosoted tie..... | 158 | " |

The whole operation for one charge of ties occupies about one hundred and thirty-two minutes, as follows, but varies slightly, however, according to the moisture in the timber:

| | | |
|---|---|---|
| Ejection vacuum..... | 13 | minutes. |
| Pumping commenced and tank filled..... | 9 | " |
| Full pressure obtained in..... | 10 | " |
| " maintained for..... | 50 | " |
| Spare creosote allowed to drip from ties..... | 50 | " |
| Total..... | 132 | " |

From the creosoting cylinder the timbers are run back into the chairing shed, where the chairs are attached to the ties by a machine (somewhat on the style of a steam hammer) which, at one stroke, drives the four fastenings for each chair. This machine will "chair" about 70 ties per hour.

The time occupied in seating, boring, creosoting and chairing 376 ties is as follows:

| | Hours. | Minutes. |
|---|---|---|
| Seating and boring | 3 | 40 |
| Running trucks into cylinder | .. | 20 |
| Creosoting | 2 | 12 |
| Withdrawing charge from cylinder | .. | 20 |
| Chairing | 5 | 14 |
| Total | 11 | 46 |

or 1 minute and 53 seconds per tie.

The cost of the operations, not including the value of the machines, is as follows:

| | |
|---|---|
| Loading white ties, per 100 | $ 36 |
| Adzing and boring, " | 62 |
| Tanking " | 64 |
| Creosote, 300 gallons at | 6.75 |
| Chairing and spiking, per 100 | 2.44 |
| | $10 81 |

or 10.81 cents per tie.

The whole of the work is done at the company's store yards at Castleton and Knottingley, and is let piece work at the above rates.

### (2.)—Great Northern Railway (Ireland).

In 1876, when a number of railways were amalgamated to form this system, the new company decided that all the ties should be creosoted, and that to insure the work being efficiently performed, it would erect suitable plant of its own for sawing, grooving and creosoting the timber to be used for ties. After being sawed, the ties are taken to the grooving machine, which forms a groove or seat for the base of flange rails by means of cutters making 2 000 revolutions per minute. Boring machinery, with twisted augers, was used for a short time, but the adoption of the improved ragged spike, which cuts its own way without splitting the tie, enables holes to be entirely dispensed with, and insures a tighter fit of the spike. After being grooved the ties are run out into the yard on a tramway of 30-inch gauge, and stacked to a height of 14 feet, alternate tiers on edge and on flat.

The cylinder is 60 feet long (6 tie lengths), 6 feet diameter, built of ½-inch plates. The safety valve is set at 110 pounds, but seldom rises; it is, however, sometimes lifted to release air and water when the pressure pumps are working. There are six tanks, of such a size that a vertical inch of the six tanks represents 156 gallons; a float is connected with a gauge and scales, which show the gallons or pounds of creosote forced into the cylinder. There are 1½-inch pipes in the cylinder, through which steam is forced to heat the creosote to 120 degrees Fahr., thus dissolving the naphthaline, etc., and rendering the creosote quite fluid. There is an air pump, 6½ by 10 inches, which exhausts the air from the cylinder, and the creosote enters by the atmospheric pressure on the tanks; the partial vacuum does not extract the sap or affect the timber. When the cylinder is nearly full, the valve is closed, air pump stopped, and the two force pumps, 3 by 4 inches, put at work. Three hours of steady pressure are required. The consumption of oil varies from 140 to 180 casks, of 36 to 38 gallons each, per week; and the quantity used annually is about 250 000 gallons. The average quantity of creosote injected is 2.35 to 2.57 gallons, or 25 to 27 pounds per tie. About nine months seasoning is customary, but a longer period is considered desirable so as to insure dryness.

"Little or no creosote can be forced into a thoroughly wet sleeper, even at high pressures, and a thoroughly dry sleeper will readily absorb a large quantity of oil, which, when solidified by exposure to the air, no moisture, either from air or wet ground, will succeed in removing."

[The information given above is briefly abstracted from a highly interesting paper: "Description of a Creosoting Yard for Railway Purposes," by Mr. W. Greenhill, M. I. C. E. I., an engineer of this railway, read before the Institution of Civil Engineers of Ireland, in May, 1886. The paper contains very full particulars, in detail, of the plant and process, results of tests, cost, etc., and is especially interesting in that it describes work done by a railway company in treating timber for its own use.]

PLATE LX
TRANS AM SOC CIV ENGNS
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TRATMAN ON ENGLISH
RAILROAD TRACK.

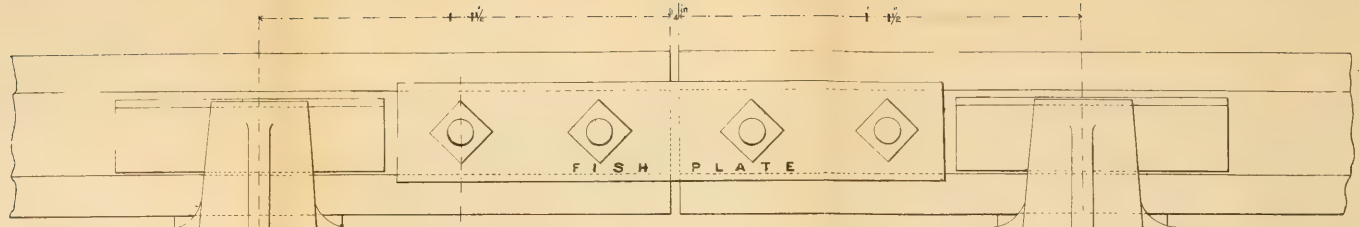
# NORTH EASTERN RAILWAY.

## SOUTHERN DIVISION.

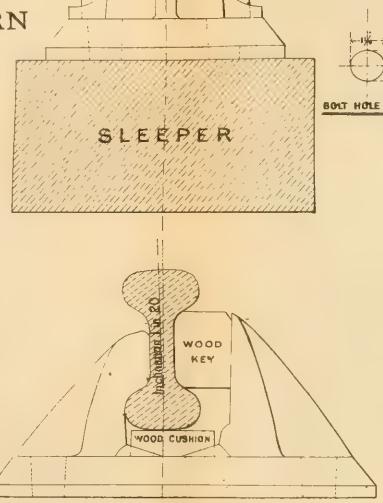
## PERMANENT WAY.

Scale Quarter Size.

| WEIGHTS. | | |
|---|---|---|
| Rail ... ... ... | 82 lbs. | per yard. |
| Chair ... ... ... | 40 ,, | each. |
| Fish Plate ... ... | 13 ,, | ,, |
| Bolt and Nut ... | 24 oz. | ,, |
| Spike ... ... ... | 22 ,, | ,, |

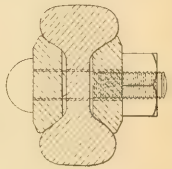



ELEVATION

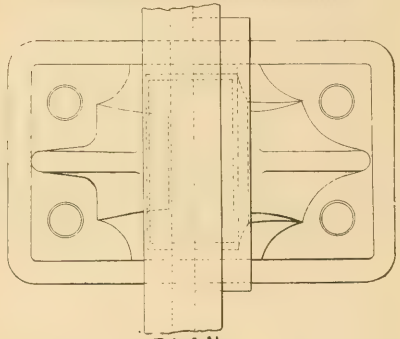



SECTION

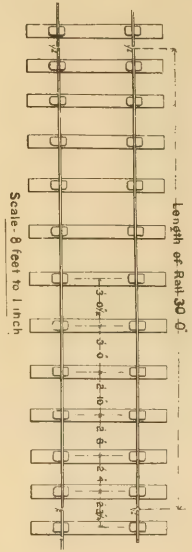
SPIKE



SECTION OF RAIL & FISH PLATES

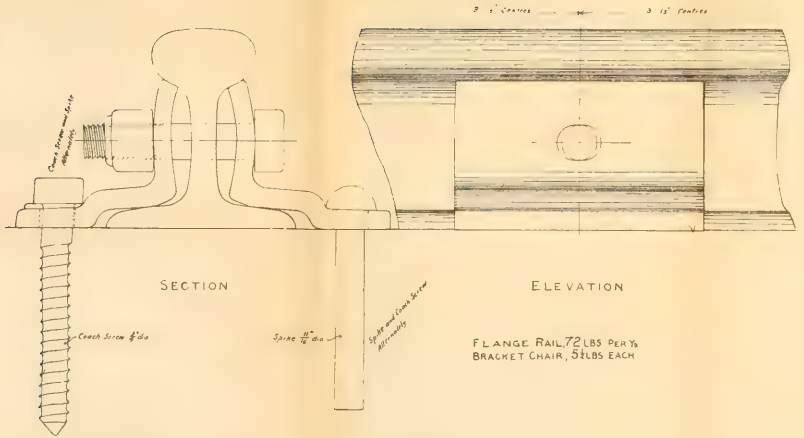


PLAN



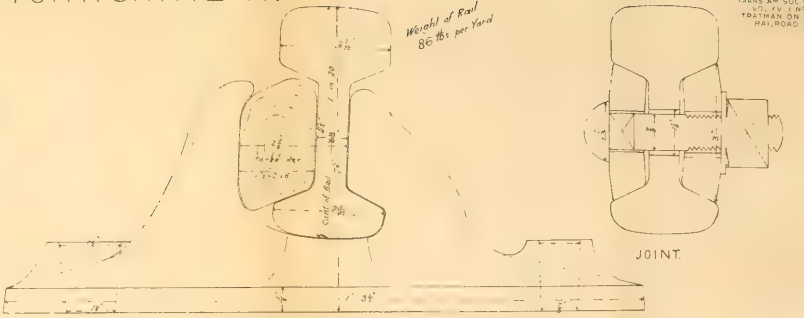
# LANCASHIRE & YORKSHIRE RY.

PLATE "A"
TRANS. AM. SOC. CIV. ENGNS
VOL. LV. NO. 388
TRAUTMAN ON ENGLISH
RAILROAD TRACK

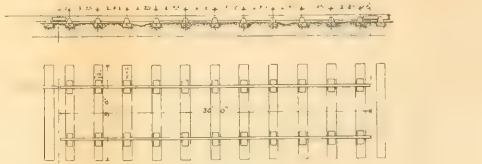



FLANGE RAIL TRACK.

FLANGE RAIL, 72 LBS PER YD
BRACKET CHAIR, 51 LBS EACH



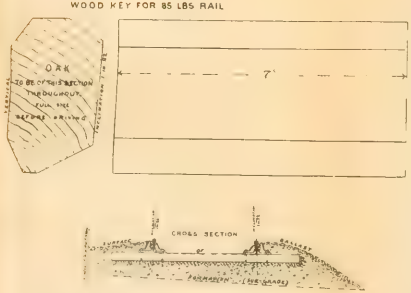

CHAIR AND BULL-HEADED RAIL.



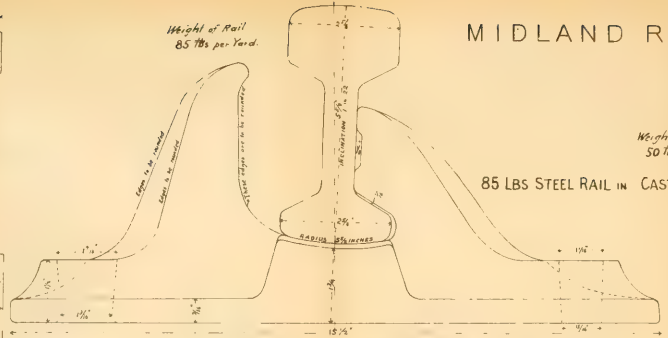

PLAN AND ELEVATION OF TRACK

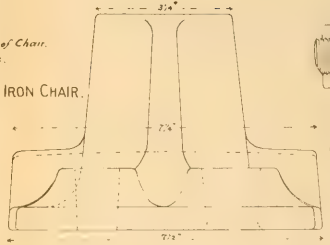
# MIDLAND RAILWAY

PLATE XXII
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVIII N° 388
TRATMAN ON ENGLISH
RAILROAD TRACK

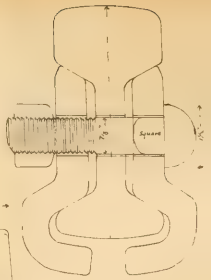


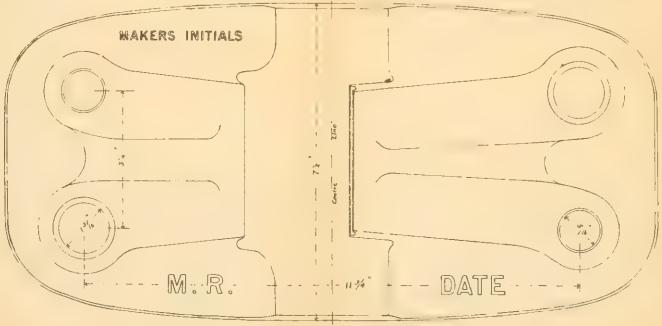

NOTE. 7" Trenails and Spike holes must be bored quite through the Sleeper.
Screws and 7" Spike nails are to be dipped in Tar before using.
Trenail inserted until ½" is exserted on the Tar after drawn.
The Keys are to be driven in the same direction as the Iron treads, wherever practicable.
Side to Fish joint is to be outside of rail.
Cesspool is to be level with top of Sleepers in the Gauge way, and level with Top of Rails in Sidings.
Gauge to be set and Drawn pin where necessary so that no water is allowed to remain.
on the Sleepers under the Ballast.
The Rails are to be laid with the LETTERS on the web of.
The Sleepers are to be laid with the same face upwards.

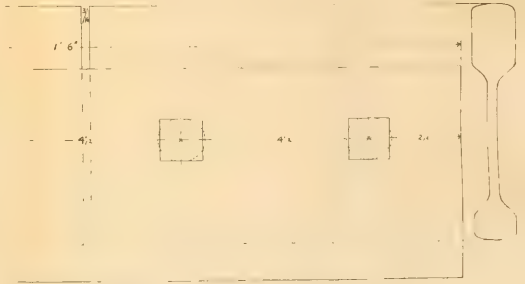



85 LBS STEEL RAIL IN CAST IRON CHAIR.



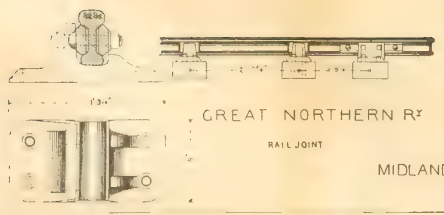




Holes in Rails 1"x 1⅛"

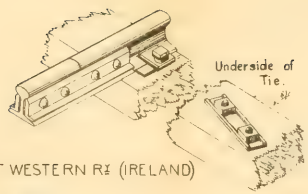
CHoles in Fish Plates. 1"x 1"

PLATE LXII
TRANS AM SOC CIV ENGRS
VOL V II Nº 388
TRATMAN ON ENGLISH
RAILROAD TRACK



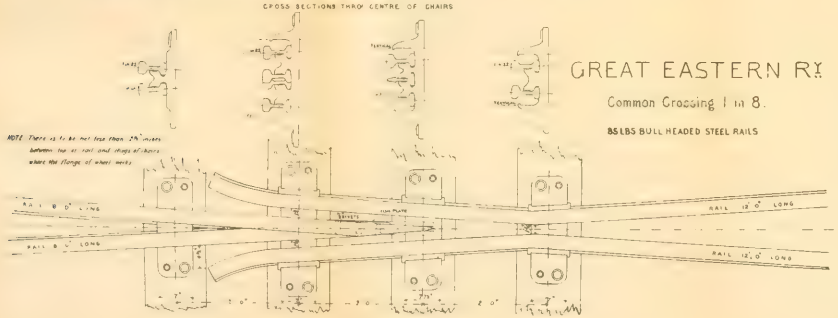
GREAT NORTHERN Rx

RAIL JOINT




MIDLAND GREAT WESTERN Rx (IRELAND)

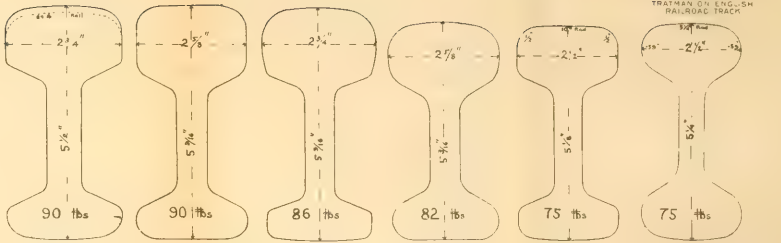
RAIL JOINT.


CROSS SECTIONS THROU CENTRE OF CHAIRS
NOTE. There is to be not less than 2½" inches between the ex. rail and flange of keeps where the flange of wheel works
RAIL 18'0" LONG
RAIL 9'0" LONG
RAIL 18'0" LONG
RAIL 9'0" LONG
RAIL 18'0" LONG

GREAT EASTERN Rx

Common Crossing 1 in 8.

85LBS BULL HEADED STEEL RAILS

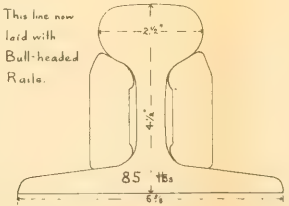



LONDON & NORTHWESTERN. | CALEDONIAN. | GREAT WESTERN. | GREAT NORTHERN. | GREAT NORTHERN(Irp). | NEW SOUTH WALES GOVT.

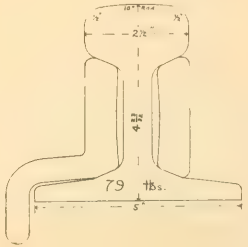
## RAIL SECTIONS

LIVERPOOL CENTRAL STATION.

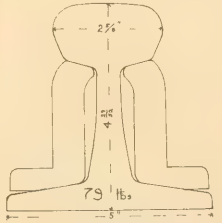
This line now laid with Bull-headed Rails.




GREAT NORTHERN.



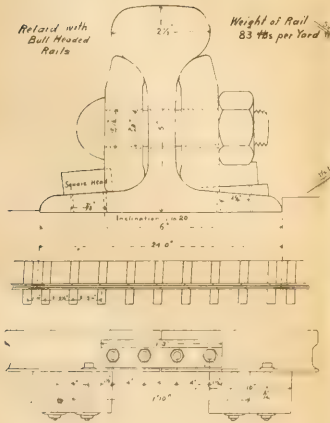

MIDLAND GREAT WESTERN (IRELAND)



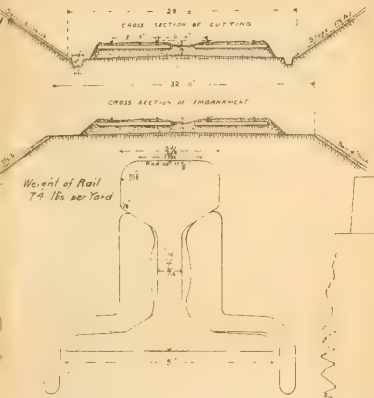
WEST RIDING & GRIMSBY. Rʸ

Relaid with Bull Headed Rails

Weight of Rail 83 lbs per Yard



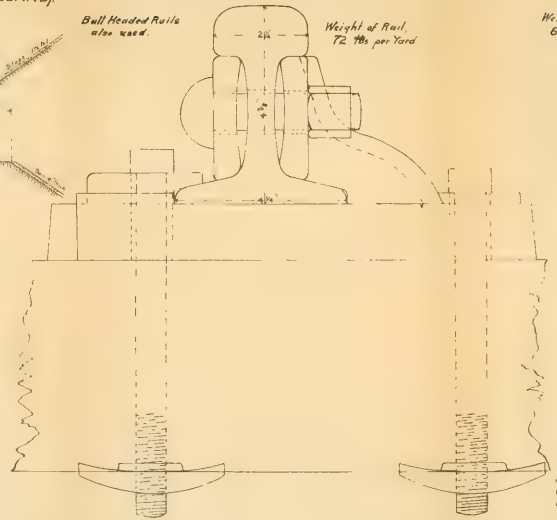

GREAT SOUTHERN & WESTERN Rʸ (IRELAND).



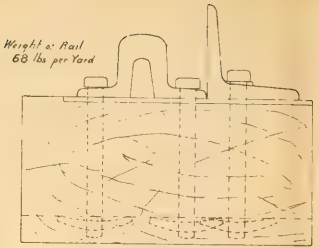

SEVERN & WYE & SEVERN BRIDGE Rʸ

Bull Headed Rails also used.

Weight of Rail 72 lbs per Yard



Weight of Rail 68 lbs per Yard



TRACK ON THE SEVERN BRIDGE.
(HALF SIZE.)

PLATE XIV
TRANS. AM. SOC. CIV. ENGNS.
VOL. XVII. No. 388
TRATMAN ON ENGLISH
RAILROAD TRACK

GREAT NORTHERN Rʸ (IRELAND).

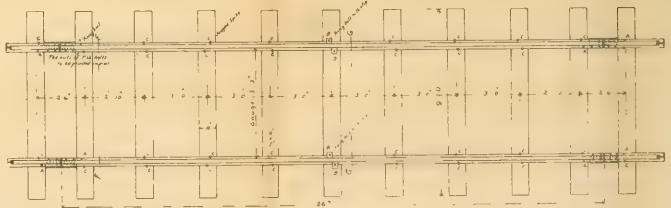
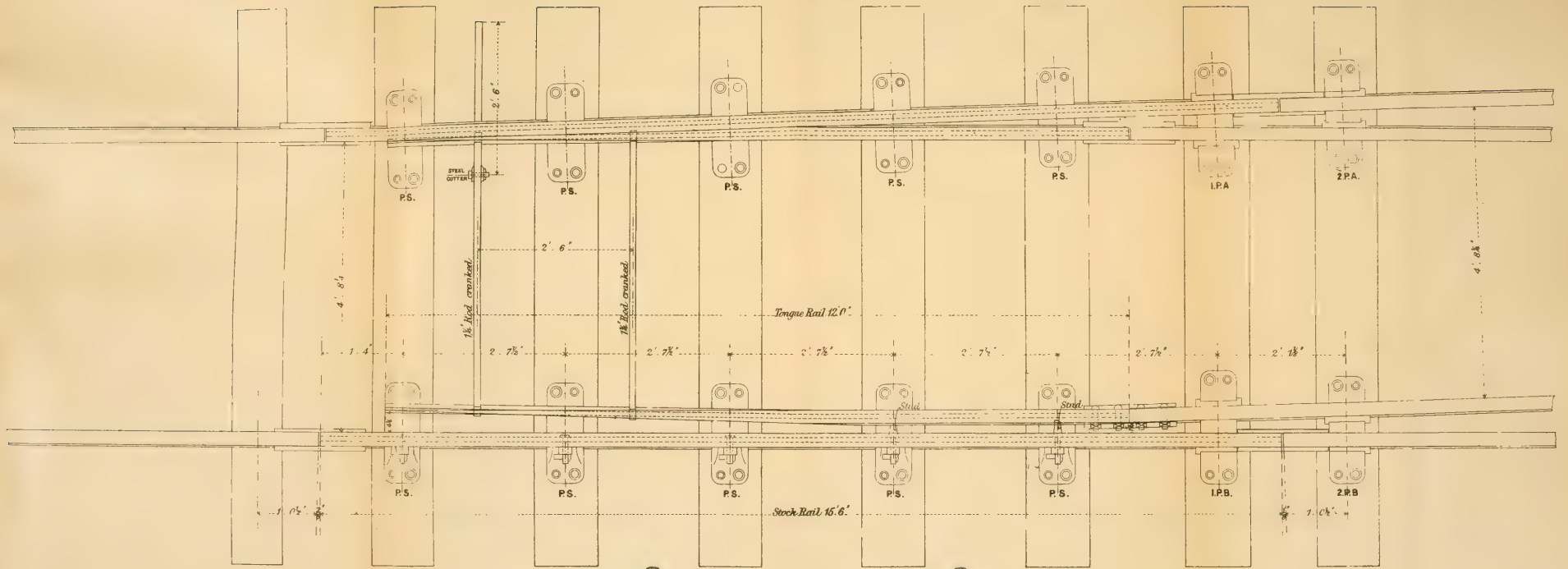


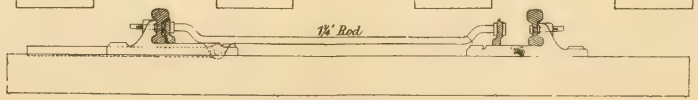
PLATE LXV
TRANS AM SOC CIV ENGNS
VOL XVIII Nº 388
TRATMAN ON ENGLISH
RAILROAD TRACK.

# GREAT EASTERN RAILWAY

## Points 12'.0" Tongues.

### 85 LBS BULL HEADED STEEL RAILS

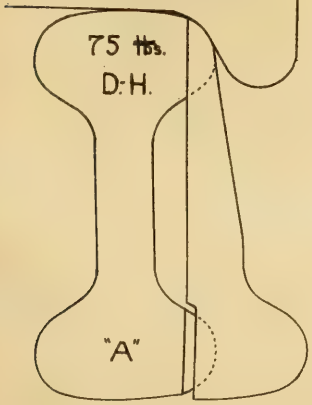


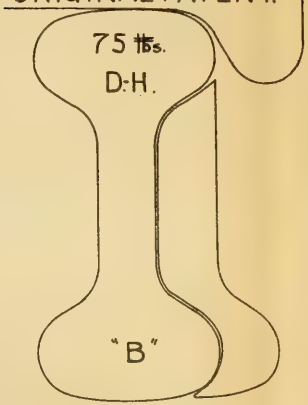

SECTION SHEWING CRANKING OF RODS.

PLATE LXVI
TRANS. AM. SOC. CIV. ENG'NS
VOL. XVIII Nº 388.
TRATMAN ON ENGLISH
RAILROAD TRACK.

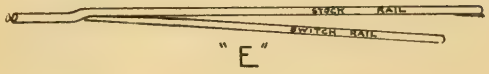
OLD SYSTEM.
NOTCHED STOCK RAIL.



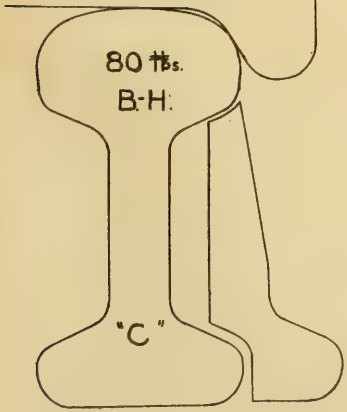

WILD'S
ORIGINAL PATENT.



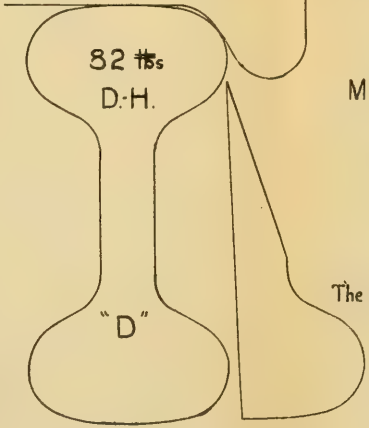

CRANKED STOCK RAIL.




CALEDONIAN RY
PRESENT PRACTICE.

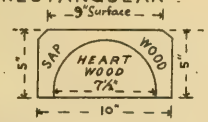



NORTH EASTERN RY
PRESENT PRACTICE.

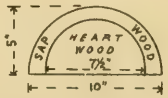



MIDLAND GREAT WESTERN RY (IRELAND).
TIMBER CROSS-TIES.

RECTANGULAR.




HALF-ROUND.




The center of the Heart Wood must be within ½-inch of the under surface of the Tie.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
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TRANSACTIONS.

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389.
(Vol. XVIII.—June, 1888.)

# MAINTENANCE—EXPENSES OF TRACK ON WOODEN AND METAL TIES.

By J. W. POST, PERMANENT WAY ENGINEER NETHERLAND STATE RAILROAD COMPANY.

READ AT THE ANNUAL CONVENTION, JULY 2D, 1888.

## WITH DISCUSSION.

Though the track of European railroads shows in material, construction and maintenance a great difference from the track on American lines, the following data concerning the use of steel cross-ties, gathered methodically since 1865 on the lines worked in Holland, Belgium and Germany by the Netherland State Railroad Company, may be of some interest to American railroad engineers.

The first trial of metal ties on the Netherland State Railroad dates from 1865, in which year 10 000 Cosijns ties were laid. In 1880 these ties, of a system now considered poor, had given satisfactory results as to the metal part during their fifteen years of service, but the oak blocks had to be frequently renewed. Moreover, the following considerations induced the company to search for a good metal tie:

*First.*—It was feared that prices of timber would gradually rise, owing to the increasing devastation of forests.

*Second.*—Even with the wood deemed best for ties, viz.: oak, it was difficult to secure satisfactory results; some lots of oak ties, severely in-

spected, appeared first-rate when new, but had to be renewed after only one year of service. The time of felling seems to be of great importance, and cannot be determined at the moment of purchase even by the severest inspection.

*Third.*—Even the best methods of impregnating proved unreliable; of ties coming from the same boiler some were quite saturated, others only on the surface; some lasted one year only, others twenty years. Uniformity in this respect is desirable for the track.

*Fourth.*—No timber merchant guarantees his ties; whereas steel ties are generally guaranteed for two years.

*Fifth.*—There is a great loss of interest during the time timber ties are piled in order to dry; whereas metal ties are often in the track before being paid for.

*Sixth.*—There is a great loss of timber ties by bursting, caused by sunshine, water, frost, driving the spikes, etc.

*Seventh.*—Timber ties being heavier than metal ties, the transport to the place where they are put in the track is more expensive.

*Eighth.*—The difficulty and cost of the respiking and readzing of timber ties, and of the replacing by new ones, increases with the daily number of trains. Ties of more durable material are desirable also from that point of view.

*Ninth.*—The selling price of old metal ties is considerably higher than the price of old timber ties.

*Tenth.*—A calculation* of the total annual sum required for purchase, laying, maintaining and renewing tracks on timber and on metal ties gave a favorable result for the metal.†

All these considerations induced the company to charge the writer in 1880 to study, both at home and abroad, the different systems of metal ties then in use, both from the point of view of manufacture and of maintenance, and to propose a method of trial enabling the company to get the most complete information possible on the subject.

This charge resulted in the following different systems of ties and fastenings being laid in the track from 1880 to 1888:

| | | | |
|---|---|---|---|
| In 1881 | 4 133 | ties, type | I. |
| " 1882 | 4 001 | " | II. |
| " 1883 | 2 089 | " | III. |
| " 1883 | 2 090 | " | IV. |
| " 1884 | 11 680 | " | V. |

* For methods of calculation see valuable report to American Society of Civil Engineers, June, 1885, on the "Preservation of Forests."

† Many important improvements introduced since have increased the advantage of metal over timber.

And from 1885 to 1888, about 126 000 ties, types VI, VII, VIII and IX, making about 150 000 ties of ten different types (including Cosijns). Of each of the types, trial lengths, under different circumstances of grades and curves, were put under special observation, every hour of maintenance-work and every renewed piece being scrupulously noted. As a base of comparison 1 120 first-rate new oak ties were laid in the track, the rails being fastened with the ordinary spikes.

At the same time different systems of fastenings were tried on the metal ties.

The Plate No. LXVII, shows the principal features of each of the types of ties and fastenings put under observation. By trying the best improvements in shape, material and manufacture, and by eliminating every year the faults of the preceding types, the writer gradually arrived at types VIII and IX of ties and type *C* of fastenings, which types having shown great advantage in every respect over the preceding types, have now been adopted as standards for this railroad.*

Types VI, VII, VIII and IX are in mild steel rolled to a variable section, strengthening at rail seats and tilt, 1.20 being obtained directly by rolling, thus preserving the steel from damage at the vulnerable spot (rail seats) by bending or pressing. These ties weigh 50 to 55 kilogrammes each, corresponding to 57 to 63 kilogrammes per tie of uniform section BB (economy 15 per cent.). Type VI, without waist, like all preceding types, I to V, had not quite the same stability as types VII, VIII and IX have; indeed, this reduction of breadth in the middle causes the principal reaction of the ballast to work at the rail seats, eliminating the balancing action of the track which takes place when the support is in the middle, particularly on badly ballasted roads or with neglected packing. Moreover, the increased height at the center gives greater rigidity to the tie.

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* Other railroads have, to their great satisfaction, followed this example. A total of about 457 300 ties (about 23 800 tons) of the Post-types VI, VII, VIII and IX is now in service on different lines of Holland, Belgium, France, Germany, Switzerland and Asia (colonies). About 272 700 more (about 12 700 tons), comprising the narrow gauge and rack road ties for Sumatra, are ordered and being manufactured now, making a total of about 730 000 ties (or 36 500 tons). See on this subject:

(*a.*) Mr. Bricka's official report to the French Minister of Public Works.

(*b.*) Mr. Kowalski's official report to the Milan Railroad Congress, 1887.

(*c*) Report of Vincennes Exhibition, 1887, highest award to Netherlands State Railroad Company and to the writer.

(*d.*) Annual Report, 1887, of the French Society for the Advancement of Industry; silver medal awarded to the writer.

The wedge-waisted tie VII is, unfortunately, of difficult manufacture, and so types VIII and IX are practically esteemed the best, and all agree that they give remarkable results. The ends are closed (Figs. 2 and 3), and grip projects downwards 2 inches into the ballast. The tests prescribed for inspection are very severe (see Figs. 4 and 5). The author executed a series of tests to establish whether annealing the ties after punching the holes does pay or not. Figs. 6 and 7 show the result; his conclusion was, that with mild steel annealing is not necessary, but is desirable if it can be done at small expense.

The ties are tarred if they have to remain a long time beside the track. The price, including two years of guarantee, varies from 22 to 26 ~~francs~~ dollars per ton.

The fastenings, type *C*, show the following improvements, gradually introduced and tried by the writer. The surface of nuts and clips is roughened to facilitate the grip of the Verona nut lock. The nuts are indented for this purpose (Figs. 8 and 9). The clips, if rolled (mild steel annealed), get three fillets (Fig. 9) for the same reason; if stamped (iron or mild steel), they are indented like the nuts (Fig. 10). In both cases the clip has a large contact with the surface of the tie in order to reduce the wear. For the same reason the head of the bolt (iron or soft manganese steel) is large (Fig. 11). The bolt must not be less than $\frac{7}{8}$ inch diameter. The collar of the bolt, which is eccentric, to enable widening of gauge on curves by turning the bolt 180 degrees, fits tight into the tie hole; this hole being rounded in the corners to avoid cracks, the bolt collar is rounded accordingly. The Verona nut locks (Fig. 12) are of the very best quality, severely tested as to elasticity and sharpness of points, and are guaranteed. The price of these improved fastenings does not exceed 24 ~~francs~~ cents per tie.

The statistical results as to cost of maintenance gathered to January 1st, 1888, on twenty-four trial lengths, are shown in the accompanying table. Columns 1 to 14 give the particulars of sections, condition of laying, types, etc., and columns 15 to 22 the expense of maintenance per day and per kilometer in francs.

The statistical data gathered to January 1st, 1887, and the close and scrupulous observations of the trial divisions, allowed the company to report seventeen conclusions to the Milan Railroad Congress in 1887. The service from January 1st, 1887, to January 1st, 1888, having fully confirmed the opinions of the company on these seventeen points, the

following conclusions are still applicable to the statistical data gathered to January 1st, 1888, as contained in the accompanying table:

1. Trials 11 and 14 are on curves of 350 meters radius and 16 millimeters per meter grade. Oak ties occupying this place previously had to be respiked every year, causing great cost of maintenance; the rail flange cut the spikes 3 to 4 millimeters, thus giving every year a gauge widening of 6 to 8 millimeters. Several ties of type III, on the contrary, taken from the track for inspection after 1 553 days of service, showed only a widening of 2 millimeters, the exterior bolts, type *A*, being worn only 1 millimeter by the rail flange. The tie surface only showed a slight amount of corrosion, and the holes were not in any way enlarged or ovalized. Considering the unfavorable conditions under which these ties were, these are very good results; in no year did the expense amount to 2 francs per day kilometer, and the average day kilometer is only 1.39 and 1.40 francs (columns 18 to 22).

2. Trials 3 and 9 being on marshy ground, the result may also be considered as favorable; in no year as much as 2 francs per day kilometer, and average day kilometer francs 0.95 and francs 0.88 (columns 15 to 22).

3. As to consolidation (about 2 300 days), the only trials comparable to the base trial No. 1 (oak ties) are trials 2, 3, 4 and 5. Though two of these four trials are under unfavorable conditions, there is no sensible difference between the average day kilometer of trials 2, 3, 4 and 5, and the day kilometer (francs 0.605) of trial 1, a very favorable result indeed, considering the following facts:

(*a*). Type I is what we now consider a poor system, each of types II to IX being great improvements. Had one of the more perfect types been used on these trials, still better results would have been obtained.

(*b*). Respiking and readzing of the oak ties of trial 1 had begun in 1886, and has to be continued in 1888 and following years, increasing the cost of maintenance with the age of the wood.

(*c*). With the trials on metal ties, on the contrary, there is a tendency shown of a decrease of expense as the permanent way becomes set.

(*d*). On trial 1 only ten oak ties had to be replaced by new ones since 1881; this renewing, however, will go on increasing with the age of the wood, thus increasing, apart from the

cost of purchase, the daily expense (work) of trial 1. The renewal of ties on the other twenty-three trials, on the contrary, was *nil* since 1881 (not one metal tie being broken), and will be *nil* for many years.

4. The day kilometer of trials 6, 7, 8, 12 and 17 does not exceed francs 0.88; those of trials 10, 13, 15, 16, 18 and 19 are below francs 0.60, though these eleven trials date only from 1883 and 1884.

5. The time of observation for types VI, VIII and IX (trials 20 to 24), has been too short to form any definite idea of the mean day kilometer; meanwhile everything tends to show that these types will give even far better results than types I to V.

6. The average expense for laying and maintaining the twenty-three trial-lengths, 2 to 24 has not been greater than would have been occasioned by the timber ties laid on the same places. The supplementary expenditure for these trials, apart from the trouble of statistics, etc., is therefore *nil*.

The close observation of the permanent way and of the manufacture of ties and fastenings led the company to the following conclusions:

7. A part of the road near Liege, twenty-five trains daily, curve of 530 millimeters radius, 16 millimeters per meter gradient, after having been carefully packed, was left for forty months without any other work than occasional nut-tightening. This shows that a good road, with steel ties, once properly packed, requires no more scrupulous attention and maintenance than one laid with timber ties; on the contrary, it would have been dangerous to have left a track situated as this was, and laid with timber ties, for a period of three and a half years.

8. The diagrams of the self-registering gauge-measure show that the gauge is much more regularly kept on metal ties than on timber (even new oak) ties.

9. The position of the rail, which often changes on timber ties, is not variable with the metal ties.

10. The lateral displacement of the track is insignificant with metal ties, even on curves of short radius, providing that the tie is closed at the end.

11. The breadth of the ballast bed may be made a little smaller with waisted metal ties (Types VII, VIII and IX) than with ordinary metal or timber ties.

12. The respiking and readzing of trial necessitated to 1888 the re-

placing of 2 bearing plates and 1 081 spikes by new ones. The renewal of fastenings on the metal ties is insignificant, especially with Type *C*.

13. Iron is not recommended for metal ties; mild steel is superior to it in every respect, viz., manufacture, inspection, rigidity and durability.

14. Alternating joints have given satisfactory results, especially in curves of short radius.

15. Suspended rail-joints have given the best results on metal ties, providing the angle splice-bars be strong and the distance between joint-ties small.

16. Types VII, VIII and IX fulfill all conditions for properly imbedding the tie. If the packing is done properly, and does not exceed 1½ feet from each side of the rail, the track can never become balancing, through the ballast working towards the middle of the tie and leaving the ends unsupported, for the shape of the tie drives the ballast towards the rail seats, both transversely and longitudinally (see Fig. 1 and section under type *C*.) Generally the ballast soon forms into a [illegible] adhering to the interior of the tie, thereby augmenting [illegible] of the track.

17. The track men, who generally abhor novelties, have soon [illegible] the steel ties and [illegible]

The [illegible] by quoting at the Milan Congress the following [illegible] report of Mr. Charles Renson, Resident Engineer of [illegible] n, which will be received with great appreciation on account of the distinguished and impartial manner in which this engineer has organized the trials of metal ties on that section:

"A single track with ties, Type VIII or IX, having twenty-five trains per day with curves, gradients, ballast, etc., as the Liege-Hasselt section, can be, after four years of consolidation, maintained in proper order at the rate of one hundred working days per year—kilometer. A gang of four men, working two hundred and fifty days a year, of which fifty days are given to other work, are able to maintain in good condition 8 kilometers of permanent way."

The Netherland State Railroad Company, having experienced the great advantage of practical experiments made on trial sections of track, has continued experiments as follows, in order to gather information on other points.

Between Tilburg and Breda, four parts of equal length were laid in 1886 on the same track, to compare the cost of maintenance and of renewal between:

1. Ordinary steel rails (33 kilograms per meter) on timber ties.
2. Heavy steel rails (40 kilograms per meter) on timber ties with two Post's steel, toothed bearing-plates on every tie.
3. Heavy steel rails (40 kilograms) on heavy Post steel ties.
4. Ordinary steel rails (33.7 kilograms per meter) on ordinary Post steel ties.

The time of observation is yet too short for any conclusion.

Between Tilburg and Breda, four parts of equal length are being laid now in the same track to compare the cost of maintenance and of renewal between:

1. Ordinary steel rails on 10 timber ties, per 9 meters of track.
2. " " 11 " 9 "
3. " " 12 " 9 "
4. " " 12 " 9 "

—with alternating joints.

Between Weurne and Helmond the same four comparative lengths are being laid on ten, eleven and [illegible] meters of track.

The information gathered by [illegible] will be of great value; not only for the [illegible] roading generally; the best [illegible] savings being a reduction of the expenses of maintenance and renewal.

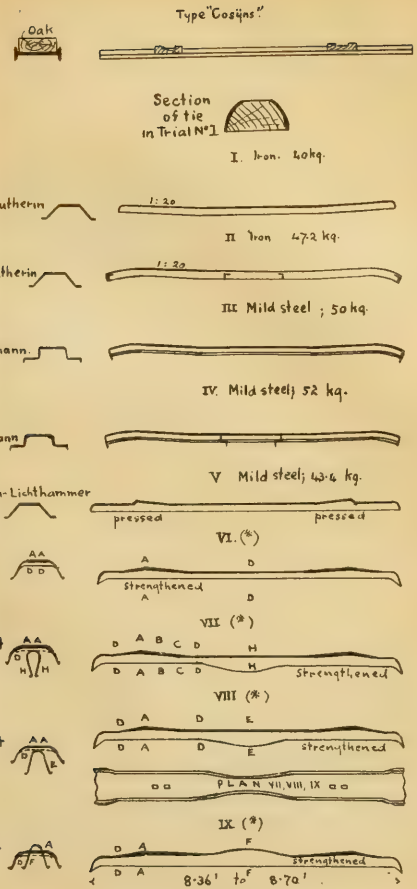
# Table of Cost of Maintenance on Trial Tracks with Wooden and Metal Ties, Netherland State Railroad Company.

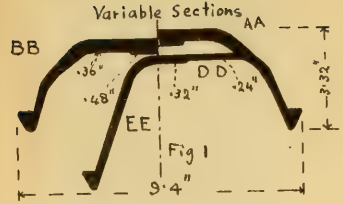
Vol. XVIII, p. 260.

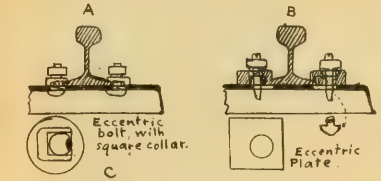
| Trial Number. | Trains per day. | Section of Line. | From | To | Gradient in millimeters per meter. | Radius of Curves in meters. | Length of Trial in meters. | Number of Ties | Types. | | When Laid. | Date when Observation Commenced. | Number of days in service. | | Cost of Maintenance in francs per kilometer per day. | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Ties. | Fasten'gs. | | | From beginning observation to Jan. 1, 1888. | 1887. | 1881. | 1882. | 1883. | 1884. | 1885. | 1886. | 1887. | From beginning ~~of construction~~ observation 1888. |
| | | | Kilom | Kilom. | | | | | | | | | | | | | | | | | | |
| 1 | 25 | Liége-Tongres ..... | 15.620 | 14.612 | 12 | 500 | 1.008 | 1 120 | Oak. | Spikes. | 1881 | July 1, '81 | 2 375 | 365 | 0 159 | 0 217 | 1.226 | 0 396 | 0 493 | 1.101 | 0.423 | 0.605 |
| 2 | 25 | Liége-Tongres..... | 16.666 | 15.620 | 12 | 750 straight | 1.046 | 1 133 | I. | A | 1881 | " | 2 375 | 365 | 1.120 | 0.423 | 0.576 | 0 195 | 1.086 | 0.538 | 0.842 | 0.650 |
| 3* | 25 | Bilsen-Hassett..... | 41.033 | 40 170 | 1 2 | straight | 0 923 | 1 000 | I. | A | 1881 | Sept. 1, '81 | 2 313 | 365 | 1 930 | 0.829 | 1.884 | 0.256 | 0.901 | 0.383 | 1.135 | 0 952 |
| 6 | 25 | Liége-Tongres..... | 7 946 | 7.432 | 16 | 1 000 | 0.514 | 600 | II. | B | 1882 | Jany. 1, '83 | 1 826 | 365 | ..... | ..... | 1.214 | 0.489 | 0.638 | 1.112 | 0.552 | 0.801 |
| 7 | 29 | Liers-Flamalle..... | 1.831 | 1.393 | level | 1 000 | 0.438 | 500 | II. | B | 1882 | " | 1 826 | 365 | ..... | ..... | 1.582 | 0.277 | 1.160 | 0.494 | 0.573 | 0.817 |
| 8 | 25 | Tongres-Bilsen..... | 25.031 | 24.570 | 8 | straight | 0 461 | 500 | II. | B | 1882 | " | 1 826 | 365 | ..... | ..... | 1.676 | 0.533 | 1.253 | 0.118 | 0.046 | 0.725 |
| 9* | 25 | Bilsen-Hassett..... | 43.625 | 43.349 | 4 | straight | 0.276 | 300 | II. | B | 1882 | " | 1 826 | 365 | ..... | ..... | 1.687 | 0.861 | 0.953 | 0 278 | 0.625 | 0.881 |
| 11 | 25 | Liége-Tongres..... | 3.790 | 3.640 | 16 | 350 | 0.150 | 201 | II. | B | 1883 | Oct. 1, '83 | 1 553 | 365 | ..... | ..... | 0 | 1.084 | 1.974 | 1.187 | 1.660 | 1.389 |
| 12 | 25 | " " ..... | 12.707 | 12.528 | 13 | 500 | 0.259 | 300 | II. | B | 1885 | " | 1 553 | 365 | ..... | ..... | 0 | 0.891 | 0.465 | 0.264 | 0.746 | 0.587 |
| 14 | 25 | " " ..... | 4.002<br>3.640 | 3.790<br>2 836 | 16 | 350 | 1.016 | 1 328 | III. & IV. | A | 1885 | " | 1 553 | 365 | ..... | ..... | 0 | 1.647 | 1.792 | 0.867 | 1.610 | 1.392 |
| 17 | 25 | " " ..... | 12.528 | 12 315 | 13 | 500 | 0.215 | 250 | IV. | A | 1883 | " | 1 553 | 365 | ..... | ..... | 0 | 1.132 | 1.111 | 0.498 | 1.000 | 0.879 |
| 21 | 25 | " " ..... | 4.412<br>4.7 5 | 4 302<br>4.748 | 16 | 530 | 0.117 | 200 | VI. | C | 1885 | April 1, '85 | 1 095 | 365 | ..... | ..... | ..... | ..... | 0.036 | 0.078 | 0.983 | 0.495 |
| 22 | 25 | " " ..... | 8.000 | 9.000 | 16 | 1 000 | 1 000 | 1 081 | VI. | C | 1887 | June 1, '87 | 214 | 214 | ..... | ..... | ..... | ..... | ..... | ..... | 0 | 0 |
| 4 | 14 | Hassett-Wychmael.. | 22 238 | 21.130 | 2 9 | straight | 1.108 | 1 200 | I. | A | 1881 | June 15, '81 | 2 390 | 365 | 0.6635 | 0.595 | 0.614 | 0.198 | 0.156 | 0.418 | 0 297 | 0.407 |
| 5* | 14 | Wychmael-Achel.... | 32.673 | 31.940 | 3 4 | " | 0.733 | 800 | I. | A | 1881 | Sept. 1, '81 | 2 313 | 365 | 1.584 | 1.027 | 0.790 | 0.326 | 0.536 | 0 569 | 0 227 | 0 632 |
| 10 | 14 | Hassett-Wychmael... | 8 408 | 7 301 | 3.9 | " | 1.107 | 1 200 | II. | B | 1882 | Jany. 1, '85 | 1 826 | 365 | ..... | ..... | 1.077 | 0.475 | 0 329 | 0 503 | 0.595 | 0.596 |
| 13 | 14 | " " .. | 1.562 | 1.218 | 6 5 | 500 | 0.344 | 400 | II. | B | 1883 | Sept. 15, '85 | 1 509 | 365 | ..... | ..... | 0 | 0 433 | 0.438 | 0 879 | 0.583 | 0 543 |
| 15 | 14 | " " .. | 1 2.8 | 0.765 | 6 5 | 500 | 0.453 | 500 | III. & IV. | A | 1883 | " | 1 509 | 365 | ..... | ..... | 0 | 0 246 | 0.412 | 0.258 | 0.429 | 0.313 |
| 16 | 14 | Achel-Eindhaven.... | 47.334 | 47.795 | 0 8 | 2 000 | 0 461 | 500 | III. | A | 1883 | March 1, '84 | 1 401 | 365 | ..... | ..... | ..... | 0.311 | 0.143 | 0.329 | 0.802 | 0.421 |
| 18 | 14 | " " .... | 47 795 | 48.256 | level | straight | 0.461 | 500 | IV. | A | 1884 | " | 1 401 | 335 | ..... | ..... | ..... | 0 299 | 0.372 | 0.553 | 0 651 | 0.471 |
| 19 | 14 | " " .... | 46.868 | 47.334 | 0 8 | " | 0.466 | 505 | V. | A | 1884 | " | 1 401 | 365 | ..... | ..... | ..... | 0.551 | 0.897 | 0.277 | 0.492 | 0.554 |
| 20 | 14 | " " .... | 52 709 | 52.032 | 1 | 2 000 straight | 0.677 | 735 | VI. | C | 1885-'86 | June 1, '86 | 579 | 365 | ..... | ..... | ..... | ..... | ..... | 0 144 | 0.252 | 0.212 |
| 23 | 14 | " " .... | 57.342.50 | 57.425 9 | 1 | 2 000 | 0.083.40 | 93 | VIII. | C | 1887 | Sept. 1, '87 | 122 | 122 | ..... | ..... | ..... | ..... | ..... | ..... | 0 | 0 |
| 24 | 14 | " " .... | 57.425.95 | 57.509 10 | 1 | 2 000 | 0.083.15 | 93 | IX. | C | 1887 | " | 122 | 122 | ..... | ..... | ..... | ..... | ..... | ..... | 0 | 0 |
| Col. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 |

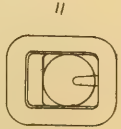
Remarks.—These trial-lengths are on single track road. 1st group, 25 to 29 trains per day; 2d group, 14 trains per day.
Rails; 38 kilograms per meter; steel angle splice bars. Ballast—Gravel, sand and cinder.
Heaviest engine on these lines 50 tons, with 13½ tons on the heaviest axle } speed up to 50 miles per hour (on some parts 60 miles per hour.)
" " other " 68 " " 13.9 " " " " "
A day's maintenance per man costs 2.19 francs; the results of Cols. 15 to 22 may be transformed into days by dividing by 2.19.
The figures in Cols. 15 to 22 give the expense for work of maintenance, not the expense for purchase of new spikes, bolts, etc.
Not one of the metal ties in this table, nor of the 124 000 steel ties in use on other lines of the Netherland State Railroad Company, has broken in the track.

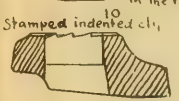
* Marshy ground.

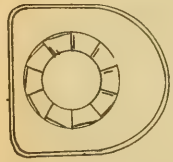


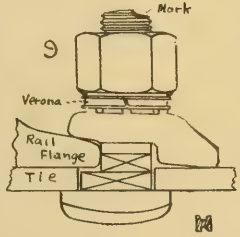



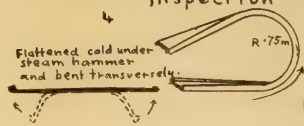



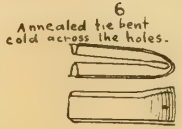



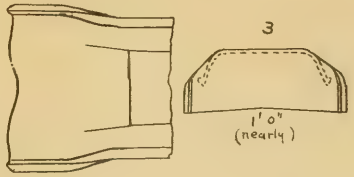





Inspection Tests.






(*) Types VI, VII, VIII and IX are in Mild Steel, rolled to variable section, strengthening at rail seats and tilt 1:20, obtained by rolling. Weight 50 to 55 kg. per tie, corresponding to 57½ to 63¼ kg. per tie, of uniform section BB, economy (15%)

# DISCUSSION.

E. E. Russell Tratman, Jun. Am. Soc. C. E.—Having received from Mr. J. W. Post, only a few days before the Convention, the paper on "Maintenance Expenses of Track with Steel and Wooden Ties, on the Netherland State Railroad," which I have transmitted to the Society by request of Mr. Post, I had not time to give as much attention as I would like to have done to this discussion.

The subject of metal railroad ties is one in which I take very much interest, and for some time past I have been engaged in making extensive investigations and collecting information with regard to practice and experience in foreign countries. In making my investigations I have been surprised at the great extent to which metal ties have been actually adopted for service, for while I knew that experiments had been made in many countries, in some cases on a quite extensive scale, I had no idea that, as a result of some of these experiments, many railroads had practically adopted these ties for regular use; this, however, I found to be the case, and several European railroad companies are now gradually substituting metal for wooden ties on their systems. I think few engineers who have not paid especial attention to this matter, realize that metal ties are in actual service, the general impression seeming to be that while many experiments have been made and are still being continued, yet that no practical results have been obtained. To this lack of appreciation of the results of foreign experience, may be attributed to a considerable degree, I think, the general indifference of American engineers to the question of metal track. The fact that the question of the future timber supply is one of serious import, does not seem to be realized, although the reports of the Forestry Division of the United States Department of Agriculture show that use and waste are playing havoc with a supply that cannot, under the present system (or want of system) of forestry in this country, be renewed in proportion to the demand. It has always seemed to me surprising that American engineers, who are usually in the van of any great step in the profession, should have paid so little attention to this very important matter; important both as to the financial economy and the practical efficiency of the track. In my opinion steel ties should be used as the standard for first-class track, and not merely as a substitute for timber, when the latter becomes scarce or expensive. For instance, on such a road as the projected New York and Boston Rapid Transit line, which is intended to be an independent line, and which will probably, when it materializes, start out with a heavy and rapid traffic, steel ties should be laid down in the first place. The same holds good for existing trunk lines, on which steel ties should be introduced, as an advancement in railroad engineering and a step towards economy.

Taken as a whole, the results of experience have been satisfactory, and the type which has been found to be the best is the cross-tie of the familiar reversed trough section. Cast-iron "bowl" sleepers are much used in new countries, and longitudinal iron sleepers are still used to some extent in Austria and Germany, but the cross-tie of trough section is the best type, as has been proved by experience and careful tests. In consequence, this form of tie is being more and more widely adopted, numerous variations of section and various styles of rail fastenings being used, in accordance with the ideas of different engineers. In England, several railroads are using steel cross-ties to a greater or less extent, but in consequence of the engineers keeping to the double-headed rail in chairs the track is very complicated and expensive, representing money wasted and lying idle in much useless metal, whereas with a good flange rail a metal track might be obtained more economical and more efficient than the present style of rails and chairs on wooden sleepers. Experience has shown that the ends should be closed, but in quite a number of cases open-end ties are used. With open ends, of course, the ties are more liable to lateral displacement, as they do not present the area of resistance presented by a wooden tie or a closed end.

As will be seen by Mr. Post's paper, the Netherland State Railroad Company has made a systematic series of trials of different types of metal ties, and the very valuable and important result of these trials has been the designing of the mild steel rolled tie of trough section, with varying thickness, now well known as the "Post" tie, which has been adopted to a very considerable extent on European lines. Mr. Post has been fortunate in having charge of a road owned by a progressive and far-seeing corporation, which has grasped the economic purposes of metal track, and encouraged its engineer in his work of investigation. The comparisons of the different systems were gone into most thoroughly, account being taken of the amount of labor, time and expense involved in maintenance, renewals and repairs, and therefore Mr. Post has been able to gradually but steadily improve the form of tie, until he has arrived at the present form, which is correct in theory and successful in practice; it is easily manufactured, and has proved in service its advantages in point of economy and efficiency. The trouble experienced with early forms of ties was that they failed by cracking, generally between the holes for rail attachments, and if made thick enough to prevent cracking they were too heavy and expensive. With the "Post" the thickness is increased at the rail seat, giving ample strength where required, but without any undue excess of weight. This strengthening is secured in the operation of rolling by the use of special machinery, and in the same operation is secured the inclination of the ends which gives the rails an inward cant of one in twenty, in accordance with European practice. Many European steel works have orders on hand for "Post" ties.

The question of rail fastenings is one almost as important as that of the type of tie, and many different plans have been tried, some simple, but the majority very complicated. All riveting causes an extra expense, but a very favorite plan is to have a "clamp" or "crab" riveted to the tie to hold one side of the rail flange, the other side being held by a bolted clamp. Mr. Post, realizing that all extra shop work is necessarily expensive, has adopted bolts exclusively, with entirely satisfactory results. It will be noted that the first type of metal tie experimented with had wooden blocks for the rails to rest upon, the idea being that the rail required an elastic seat. This seriously impaired the general efficiency of the tie, for the wood rotted and gave constant trouble, so that this form of tie was soon abandoned. It has been conclusively proved by experience with various types of ties in different countries, that such a wood-bearing is not only unnecessary, but a positive disadvantage, and that the track is satisfactory to railroad men and travelers when the rail is fastened directly on the metal tie, and therefore no wood should be used at all, but a metal track should be entirely of metal. The introduction of metal ties has been hampered by the attempt to secure a "cheap" tie. The objects in using metal are to obtain economy in maintenance and efficiency in operation, and neither of these objects can be obtained by using a tie which is "cheap." Every desirable feature cannot be combined in one piece of steel, and if the tie is to make the track safer, reduce the maintenance expenses, keep the road in better condition, and far outlast the wooden tie, it must have sufficient metal to insure these advantages. You need to have, and to pay for, enough metal to make an efficient tie; but you need not have, and need not pay for extra metal that is mere dead weight. With ties, as with rails, the design and manufacture are equally as important points as the weights, and the rail fastenings no less important.

Two points need to be considered in designing or adopting a metal track, viz.: Economy and simplicity. Cheapness is very far from being economy, being in fact directly opposed to it. Simplicity is necessary, both for economy and efficiency, as the track which, while possessing ample strength, is the most simple in its construction, will give the least trouble, and consequently involve the least expense for maintenance. A good metal track, once well laid, is in itself a source of economy in maintenance and operation, and it is to be hoped that this type of track will soon be a feature of first-class American railroads.

In nearly every large country but America, and in many of the smaller countries, metal ties have been experimented with, and I would strongly urge that more practical attention should be paid to so important a matter by American engineers, railroad men, and steel manufacturers.

AMERICAN SOCIETY OF CIVIL ENGINEERS.
INSTITUTED 1852.

TRANSACTIONS.

NOTE.—This Society is not responsible, as a body, for the facts and opinions advanced in any of its publications.

390.

(Vol. XVIII.—June, 1888.)

# REPORT OF THE COMMITTEE ON THE COMPRESSIVE STRENGTH OF CEMENTS AND THE COMPRESSION OF MORTARS AND SETTLEMENT OF MASONRY.

READ AT THE ANNUAL CONVENTION OF 1888.*

In the report made in July last, mention was made of the Watertown experiments,† but the results were but partly given, and your Committee propose at this time to discuss them as a whole.

The first tests to be noticed are compressive tests of three kinds of bricks, viz.:

*First.*—Hard-burned face bricks from North Cambridge, Mass. The average pressure at which flaking-off occurred in three specimens was 7 100 pounds per square inch.

The specimens crushed at an average of 13 925 pounds per square inch.

*Second.*—Three hard-burned common bricks from the same place

* Committee—Messrs. F. Collingwood, D. J. Whittemore, W. W. Maclay, T. C. McCollom, George F. Swain and A. V. Abbott.

The substance of this report was given verbally by the Chairman at the Annual Meeting, January, 1888. It was completed, and with the diagrams presented at the Convention.

† See "Report of the Chief of Ordnance for 1884," Senate Doc. No. 35, First Session, 49th Congress.

flaked at an average pressure of 8 800 pounds per square inch, and crushed at an average pressure of 18 337 pounds per square inch.

*Third.*—Three "Bay State" medium bricks from Cambridge and Boston flaked at an average of 6 620 pounds, and crushed at an average of 11 406 pounds per square inch.

Flaking occurred with many specimens at about 5 000 pounds.

Passing to cement tests, we must express our regret that the tests were not made with more definiteness of plan, as it is impracticable to institute comparisons. Those on neat Dyckerhoff Portland cement are quite full at twenty-two months' age, in the form of neat cement. This gives high results, but not so valuable as if made on mixtures ordinarily used.

Again, the Norton cement is tested at forty-six months, mixed 1½ and 3 parts sand to 1 cement.

The Newark and Rosendale was tested at twenty-seven months' age, mixed 1 to 3 (but five cubes, so far as this investigation is concerned, being of use). It was also tested slightly in concrete.

The packings used in testing were variable. Experiments showed a loss of strength of about 25 per cent. at rupture, when the specimens were packed with wood, as compared with those where brass strips or plaster of Paris were used; and the latter gave the most uniform results of all.

The National Portland was quite fully tested in cubes forty-six months old, mixed 1 cement to 3 sand.

Six cubes of each dimension, from 1 to 12 inches, of Dyckerhoff Portland were tested. They were molded in pine boxes on a blue-stone flag, and were tamped with a piece of hard wood as a rammer, struck by a four-pound hammer.

On the contrary, the large cubes of the other cements were rammed with an iron rammer 2 feet long and 1 inch diameter, with a conical point.

Table No. 1 and the curves on Plate No. LXVIII give the average results from the Dyckerhoff Portland for the 8 to 12-inch cubes (there being five of the 8-inch and six of each of the others), and also for three 12-inch piers respectively: No. 79½, 12 inches; No. 77½, 18 inches; and No. 78½, 24 inches high, built each of three prisms.

By reference to the individual tests it will be seen that the blocks giving the greatest strength at rupture do not always give the least compressions. The three piers give about the same strengths. The 11

and 12-inch cubes were packed with plaster, and the other cubes, etc., with brass strips.

The 6-inch Portland cubes, of which curves are shown, were from an unknown brand, and were also packed with brass strips. The error arising from this cause is very plainly shown by the curve.

It will be noted that the 11 and 12-inch cubes gave from one-third to one-half less compression than the smaller ones, showing the superiority of the plaster packing.

The other cement and concrete tests were with plaster of Paris beds.

The concrete cubes of the Newark and Rosendale cements gave 21 per cent. greater strength than the mortar cubes of the same age; but the tests of Rosendale are too few for exact comparison.

The cubes failed generally, by splitting off at the sides (see figure, page 202), the remaining portions forming two truncated pyramids, the smaller ends facing, and their bases formed by the two bed surfaces. There was occasionally a tendency to develop pyramids with the apexes overlapping.

Prisms failed in a similar manner.

Before final fracture occurred, snapping sounds were heard, and cracks were exposed to view on the sides of the specimens.

The average resistances of different cubes and prisms were as follows:

| Cubes. | | Prisms. | |
|---|---|---|---|
| Nominal dimensions. | Average resistance per square inch. | Nominal dimensions. | Average resistance per square inch. |
| | Pounds. | Inches. | Pounds. |
| 1-inch cubes. | 5 895 | 4 x 4 x 1 | 16 460 |
| 2 " " | 7 053 | 4 x 4 x 2 | 6 370 |
| 3 " " | 5 892 | 4 x 4 x 3 | 6 005 |
| 4 " " | 4 859 | | |
| 5 " " | 4 611 | 8 x 8 x 2 | 9 885 Including broken specimen. |
| 6 " " | 4 272 | 8 x 8 x 2 | 10 664 Excluding same. |
| 7 " " | 4 987 | | |
| 8 " " | 4 865 | 8 x 8 x 3 | 6 168 |
| 9 " " | 4 745 | 8 x 8 x 4 | 5 952 |
| 10 " " | 4 761 | 8 x 8 x 5 | 6 020 |
| 11 " " | 5 381 | 8 x 8 x 6 | 5 771 |
| 12 " " | 5 435 | | |

The 2-inch cubes were strongest, and the strength decreased to the 6-inch, then rose irregularly to the 12-inch. Two of the latter were not

fractured at 800 000 pounds, above which it was not considered prudent to try the machine.

Of the prisms, the shorter in each case shows the greater strength. Three 12 x 12 x 2-inch prisms used as a pier and supporting the pressure through a 10-inch cube of freestone failed at 6 566 pounds per square inch. Cracking sounds were heard at 5 522 pounds.* A 12 x 12 x 4-inch failed at 4 585 pounds; a 12 x 12 x 6-inch at 4 821 pounds, and 12 x 12 x 8-inch at 4 496 pounds.

Of mixtures of Norton's cement, the author states that cubes mixed of 1 cement to 1½ sand, gave 81 per cent. higher average results than of 1 cement to 3 sand. The average compressive strength for the first was 1 545 pounds per square inch, being 2 050 for 4-inch to 1 250 for 16-inch; and for the second 854 pounds, being 1 324 for 4-inch to 768 pounds for 16-inch.

For concrete cubes, made of 1 part Norton's cement, 1½ sand, and 6 broken stone, the average strength was 1 545 pounds, varying as before from 2 320 to 1 440 for 4 to 16-inch cubes.

For concrete of 1-3 and 6, the average was 1 021 pounds, varying from 1 635 for the smaller to 843 for the 16 inches; the first mixture being about 50 per cent. stronger than the second. Singularly, the mortar and concrete of the first mixture give the same strength while the concrete is in the second mixture, 19.6 per cent. stronger than the mortar.

An interesting experiment, as showing the elasticity of the material, was made with a 12-inch cube of National Portland cement mixed 1 to 3.

The load was run up gradually to 800 000 pounds with but slight injury, and then released, the compression being .0530 inches.

A second application of same load increased the compression 13 per cent., or to .0600; being again released, a third application increased it 12 per cent. more, or to .0665, and after sustaining the load ten minutes this had increased 16 per cent. more, or to .0752, a total increase of 42 per cent. The permanent set was at release .0415, diminishing in six minutes to .0405. A fourth application gave a compression of .0810, increasing in ten minutes to .0930. On release the set diminished at once to .0550, and later to .0532, the same as at the first release. A final ap-

*The author reckons this on the basis of the area of the freestone prism. If the area of the cement prisms be used, the figures would be about two-thirds as much. The lines of rupture would indicate a *mean* as the correct method.

plication of the load gave a compression of .1020 inches, increasing in two minutes to .1210, when the cube went to pieces; the whole experiment occupying one hour and twenty minutes.

The effect of adding lime to Portland cement mortar is in every case to diminish its strength; its action in this respect is stated to be "much more serious with Portland than with Rosendale, weakening both to such an extent that practically there is little difference in the resulting mortars, either as regards strength or compressibility."

The Rosendale cement used in the tests would seem to have been below the usual standard of excellence.

As to brick tests, the crushing strength of single bricks is largely in excess of that of brick piers.

Single bricks between rigid platforms evidently occupy a more favorable position for strength, than when between other bricks or mortar cushions of less strength.

Failure occurs in detail, first by flaking of the edges and corners, and at last when the final pressure is reached by a general disintegration.

One 6-inch cube of plaster of Paris was tested. It acted much like Portland cement, and gave a co-efficient of compression per 100 pounds of .00043 up to 200 pounds and .00028 from 0 to 800 pounds. Crushing occurred at 1 981 pounds, with a total compression on one foot of .08 inches.

With this general statement of results we pass next to the question, which is the real one for which we are in search, viz.: what is the co-efficient of compression of each material tested?

If we refer to Plate LXVIII, showing the curves resulting from pressures and corresponding compressions of the Dyckerhoff Portland cement mixed neat, at twenty-two months' age, we find that without exception there is a greater compression shown at the beginning than after the pressure has reached about 300 to 400 pounds per square inch.

We find also that after passing this pressure the curves are practically straight and nearly parallel up to 3 000 pounds and over.

Again, the smaller cubes show more initial compression than the larger, and the piers also show more compression than the large cubes.

Now all the cubes from 8 to 10 inches inclusive were either without packing or leveled with brass strips; and we find such notes as these: "brass strips, .02 and .015 inches thick under opposite corners," "compression faces, .005 inch convex," etc. The 11 and 12-inch cubes were

packed with plaster of Paris of total thickness .02 to .06 inches, and the three 12-inch square piers each had two joints in addition.

Bearing in mind these differences, we must conclude that in the case of the smaller cubes and the piers there is a greater proportional loss of motion before the specimens come to full bearing, which introduces an error in the compression curve up to 300 to 400 pounds' pressure, and a constant error through the whole.*

Referring to the curves shown, we find that the average of the twenty-nine cubes and three prisms is practically straight from the 400 pounds' point to the 3 800 pounds' point, and gives a co-efficient for the whole of

$$\frac{.03077'' - .00487''}{(3800 - 400) \times \frac{12}{100}} = .0000635 \text{ per 100 pounds of load.}$$

If we take the curve for the 12-inch cubes we get

$$\frac{.01983'' - .00293''}{(3\,000 - 300) \times \frac{12}{100}} = .0000522 \text{ per 100 pounds of load.}$$

The 8-inch curve in like manner gives

$$\frac{.01920'' - .00360''}{(2\,000 - 300) \times \frac{12}{100}} = .0000764 \text{ per 100 pounds of load.}$$

If we produce the straight lines giving these average co-efficients back to the line of abscissas, we find that the line at the 12-inch curve cuts off .001-inch, and that on the average curve and the 8-inch curve about .002-inch, and it would seem that the method just pursued gives the nearest approximation to the truth obtainable from these tests.

The records show that the upper points taken are well within the points where failure begins to be manifest. In one case only was there any cracking at as low a pressure as 1 600 pounds, the average at which snapping sounds or cracking occurred being 4 600 pounds per inch.

The set in each test was first measured at 700 to 1 500 pounds, and from this pressure up to about two-thirds of that at rupture, the increase in set progressed nearly uniformly with the pressure.

As a conclusion from all these tests we may reasonably conclude that for this brand of cement, mixed neat at twenty-two months old the co-efficient of compression in mass is about 0.100005 per 100 pounds, since the 12-inch cubes approach nearest to a continuous mass.

* It will be seen that about .005 of an inch is the greatest error implied by this supposition, a loss of motion very easily realized.

We come next to the three 6-inch cubes of Portland at fourteen and one-half months' age (see Plate LXVIII). The same phenomena of an almost absolutely straight curve from 300 to 2 200 pounds is noticeable. Produced back it strikes the line of abscissas at .008-inch. The resulting co-efficient is

$$\frac{.0298 - .0110''}{(2\,200 - 300) \times \frac{1}{1000}} = .000824 \text{ per 100 pounds of load.}$$

In subsequent results we will substitute the letter $c$ for the constant $\frac{1}{1000}$ pounds.

The last experiments on neat cement are those made by the Committee, on cement cylinders 24½ inches long and 4⅛ inches diameter (see Plate LXVIII and Table No. 2). These comprise two cylinders of neat Portland at twenty-eight days' age, one at six months, and one previously reported at one hundred and four days. Of the first and last of these we find the anomaly, as compared with all the previous results, that the compression is least at the beginning. The same tendency is shown in the concrete cylinders. The cause of this is not apparent, but may be determined by further tests. Taking the twenty-eight day tests, and averaging the curve between 100 and 700 pounds, we get a co-efficient.

$$\frac{.0198 - .0020''}{(700 - 100) \times c} = .0002472 \text{ per 100 pounds.}$$

This three-and-a-half months' test gives us an average from 100 to 1 000 pounds, as follows:

$$\frac{.0294 - .0116''}{(1\,000 - 100) \times c} = .0001648 \text{ per 100 pounds.}$$

This differs from the result as stated in previous report on this specimen, since it throws out the sharp initial compression up to 100 pounds.

The curve for the six months' test is convex throughout, but an average between 400 and 1 680 pounds gives

$$\frac{.0200 - .0032''}{(1\,680 - 400) \times c} = .0001094 \text{ per 100 pounds.}$$

Arranging the results in the order of age, we have as follows:

| | | | | | |
|---|---|---|---|---|---|
| At 28 days (say one month) | from | cylinder | test | a co-efficient of | .0002472 |
| " 3½ months | " | " | " | " | .0001648 |
| " 6 " | " | " | " | " | .0001094 |
| " 14½ " | " | 6-inch cubes, | | " | .0000826 |
| " 22 " | " | 12 | " | " | .0000522 |
| " " " | | 8 | " | " | .0000764 |
| " " " | | Av. of 29 cubes and 3 piers | | | .0000635 |

If the ages be plotted as abscissas and co-efficients as ordinates, it is evident that the curve thus formed would become parallel to the axis of abscissas after a sufficient time.

The twenty-two months cubes were from a different brand of cement from the others, and the result may be affected in a measure.

We pass next to cubes of National Portland cement mixed one cement to 3 sand, and forty-six months old (see Table No. 3, Plate LXIX). Of these two each were tested of 8 × 12 and 16-inch dimensions, giving co-efficients as follows:

The average of the 8-inch gives between 300 and 1 400 pounds for 12 inches length.

$$\frac{.0163 - .0062''}{(1\,400 - 300) \times c} = .0000765$$

The 12-inch give $\frac{.0094 - .0023''}{(1\,300 - 300) \times c} = .0000592$

" 16 " $\frac{.0071 - .0018''}{(1\,200 - 300) \times c} = .0000491$

The average of all is $\frac{.0101 - .0034''}{(1\,200 - 300) \times c} = .0000620$

We have next some tests on National Portland cement concrete, forty-six months old, mixed, one cement, 3 sand and six broken stone (see Table No. 3, and Plate LXIX). These give co-efficients as follows:

Two 8-inch cubes give approximately $\frac{.0178 - .0040''}{(1\,500 - 100) \times c} = .0000821$

Two 12 " " $\frac{.0115 - .0026''}{(1\,200 - 180) \times c} = .0000727$

Two 16 " " $\frac{.0085 - .0010''}{(1\,300 - 100) \times c} = .0000521$

The average of all gives approximately $\frac{.0123 - .0022''}{(1\,300 - 100) \times c} = .0000701$

The interesting result appears that 16-inch cubes of forty-six months' concrete give equal compression with 12-inch cubes twenty-two months old, mixed neat; also the 12-inch concrete corresponds with the 8-inch cement.

The average strength of the neat cement cubes was 2 411 pounds per inch; and of the concrete, 2 899 pounds.

The Committee would, in this connection, present some tests made by them on cylinders 24½ inches long by 4½ inches diameter (see Plate LXVIII, Table No. 2). The specimens consisted of one cylinder, twenty-

eight days old, mixed, 1 of Portland cement to 2 of sand; two of the same age, mixed, 1 to 3, and one six months old, mixed, 1 to 3.

The co-efficients obtained are as follows:

1 cement, 2 sand, twenty-eight days, $\frac{.0187 - .0031''}{(400 - 100) \times c} = .000433$

1 " 3 " " $\frac{.0282 - .0057''}{(400 - 100) \times c} = .000625$

" " 3 " six months, $\frac{.0139 - .0026''}{(500 - 100) \times c} = .000235$

It will be seen that these results are about two and one-half times those reached with the neat cement cylinders in corresponding times, showing that where it is important to have the least possible compression in work, the use of neat cement is indicated.

We have next to examine some tests of Rosendale (natural) cements. These are too few in number to base any positive deductions upon (indeed, this is true in a measure of all the results given), but the Committee hope to supplement them in the future.

We have first, two cubes each 8 inches, 12 inches and 16 inches of Rosendale cement mortar mixed 1 cement, 1½ sand at forty-six months' age (see Plate LXIX, Table No. 4).

The average of the 8-inch gives $\frac{.0163 - .0030''}{(900 - 200) \times c} = .0001584$ per 100 lbs.

" " 12 " $\frac{.0132 - .0049''}{(700 - 200) \times c} = .0001383$ "

" " 16 " $\frac{.0139 - .0041''}{(800 - 200) \times c} = .0001361$ "

" " 6 cubes gives $\frac{.0127 - .0040''}{(700 - 175) \times c} = .0001381$ "

To avoid confusing the diagram the average lines in some cases are omitted.

Six cubes of corresponding sizes at 46 months' age, mixed 1 to 3, give:

The average of the 8-inch gives $\frac{.0167 - .0051''}{(500 - 100) \times c} = .0002417$ per 100 lbs.

" " 12 " $\frac{.0083 - .0019''}{(400 - 100) \times c} = .0001777$ "

" " 16 " $\frac{.0098 - .0027''}{(400 - 100) \times c} = .0001972$ "

" " 6 cubes gives $\frac{.0108 - .0032''}{(400 - 100) \times c} = .0002111$ "

Comparing these results with the National Portland of same age and mixture we find them to be about four times as much.

The average strength at crushing of the 1 to 1½ mixture was 1 386 pounds, and of the 1 to 3 mixture 714 pounds per square inch; and the compression of the latter was about one and one half times that of the former.

Six cubes of Rosendale cement concrete at forty-six months' age mixed 1 cement, 1½ sand and 6 broken stone, gave (see Table No. 5, Plate LXIX).

The average of 8-inch gives $\frac{.0249 - .0058''}{(800 - 100) \times c} = .0002274.$

" 12 " $\frac{.0170 - .0021''}{(800 - 100) \times c} = .0001774.$

" 16 " $\frac{.0098 - .0023''}{(700 - 100) \times c} = .0001042.$

Average of all..... $\frac{.0170 - .0034''}{(770 - 100) \times c} = .0001692.$

Six cubes concrete of a mixture of 1 Rosendale to 3 sand and 6 broken stone at forty-six months' age, gave:

For 8-inch gives $\frac{.0261 - .0075''}{(600 - 100) \times c} = .0003100$ per 100 pounds.

12 " $\frac{.0102 - .0018''}{(500 - 100) \times c} = .0001750$ " "

16 " $\frac{.0100 - .0022''}{(500 - 100) \times c} = .0001625$ " "

Average of all.. $\frac{.0139 - .0038''}{(500 - 100) \times c} = .0002104$ " "

The crushing strength of the concrete with 1½ parts sand was 1 483 pounds, and with three parts sand 824 pounds average per square inch. The crushing strength of the 1 to 3 to 6 mixture with National Portland cement was 2 899 pounds, or three times that of the Rosendale, while the compressions were from about one-half to one-quarter.

Another brand of Rosendale cement mixed 1 cement, 2 sand, 3 gravel and 4 broken stone at twenty-two months old gave for 1 cube, each size, as follows:

$$\text{10-inch cube } \frac{.0132 - .0013''}{(600 - 100) \times c} = .0001983$$

$$\text{12 “ } \frac{.0153 - 0026''}{(600 - 100) \times c} = .0002117$$

$$\text{16 “ } \frac{.0089 - 0022''}{(500 - 200) \times c} = .0001861$$

$$\text{18 “ } \frac{.0119 - 0022''}{(600 - 100) \times c} = .0001617$$

$$\text{Average of all } \frac{.0104 - 0021''}{(500 - 100) \times c} = .0001729$$

It will be noted that in all cases the averages have been taken from the average curves, rather than by averaging the co-efficients, although they do not differ greatly.

Two cylinders $24\frac{1}{2}$ x $4\frac{1}{8}$ inches of a mixture of 1 part lime, 2 parts pozzuolana, and 3 parts quartz by weight (or 1 each by volume) were tested as follows, giving the following results on 12-inch length:

| No. of Test. | Age. | Pressure per inch in pounds. | | | | | | Ultimate strength per square inch. Pounds. |
|---|---|---|---|---|---|---|---|---|
| | | 100 | 200 | 300 | 400 | 500 | 600 | |
| 20 | 3 mos. | .0090 | .0170 | .0240 | .0254 | .... | .... | 524 |
| 21 | 6 “ | .0049 | .0123 | .0232 | .... | .... | .... | 449 |
| 22 | 6 “ | .0029 | .0053 | .0084 | .0138 | .0204 | .0340 | 749 |

### Brick Piers.

One of the most important series of tests in the Watertown record is that of thirty-three brick piers of various dimensions and lengths. The bricks were laid on the bed, with joints broken in every course, excepting in two cases. Their ages ranged from fourteen to twenty-four months. Compression measurements were taken within the gauged length along the center line. Contact of the pier with the beam of the micrometer was made through blocks carrying conical spur points clamped to the bricks. If these measurements could have been made on opposite sides, so as to throw out all effect of flexure, if any, it would possibly have given more uniformity in results.

The piers seem to have been packed with brass strips against steel cushions, in testing.

Loads were applied in regular increments, measuring the compression at each, and returning to zero occasionally to determine the set.

Cracks made their appearance at the surfaces of the piers, and were gradually enlarged before maximum loads were reached. Final failure

occurred by partial crushing of some bricks, and enlargement of the cracks. These took a longitudinal direction, and occurred in the bricks of one course opposite the end joints of adjacent courses.

Snapping sounds were heard long before cracks appeared; in one case at 200 pounds, another at 300, in about three at 400, and four at 500 pounds per square inch. In one case it ran to 1 800 pounds, and in a large number at 1 100 to 1 500, the average being about 900 pounds.

Piers laid in Portland cement showed the highest resistance, showing that the quality of the mortar has much to do with the strength of brick work.

The experiments seem to show that, when lime mortar is used, the yielding was much of it in the joints. In one respect the curves shown, Plates LXX and LXXI are misleading, for the following reason: the piers were transported to the testing machine in a fixture consisting of two cast-iron plates, which were set on the ends of the piers in plaster of Paris. These were joined by wrought-iron tie rods provided with turn-buckles, by tightening which the inclosed pier was placed in a state of compression. This compression was often greater than the initial loads applied, so that the early readings are not strictly correct. This result is most conspicuous in the piers laid in weak mortars.

The second application of a given load (after release from the first application), usually caused an increase in the total compression, although not always. The opinion is expressed that repeated loading would ultimately destroy a pier; but as this increased compression sometimes occurs with loads as low as 150 pounds per inch with cement mortar, the theory is questionable. The remarkable fact comes out by one of the experiments that under application of a lighter load after a heavier one, the set perceptibly diminishes, and this occurs even quite near the load causing rupture.

For example, a pier 12 inches square, 73 inches high, gauged length 50 inches, gave at 139 pounds per square inch a total compression of 0.0103 inches, increasing in five minutes to .0109 inches. On release to 70 pounds, the set measured .0065. At 348 pounds the compression was .0504, increasing as before to .0527. On release to 70 pounds, the set was .0328, diminishing to .0327 in five minutes.

Again, at 556 pounds, the compression was .0955, increasing to .0994. On release, as before, the set was .0653, after five minutes, .0649, and after sixty-five minutes .0646. At 694 pounds, the first crack appeared,

and compression after five minutes was .1334, diminishing on release to 70 pounds to .0908, and after five minutes to .0902. At 900 pounds the figures were (in the same sequence) .1872, .1908, .1345 and .1377 inches, respectively. Total failure occurred at 1 210 pounds per inch.

Piers in lime mortar, with joints broken every sixth course, seemed to be stronger than with joints broken every course; but more experiments are required to substantiate the statement.

Hollow piers were, for the same mortars, of about the same strength as solid, per square inch of solid section.

A terra-cotta cylinder, made up of three segments, each 5½ inches high, joined with neat cement, gave a co-efficient for 12 inches of about .000102.

A pier 12 inches square, 50 inches high, within gauge marks, laid up in Portland cement, neat, at nineteen and one-half months' age, gave (see Table No. 6, Plate LXX.)

$$\frac{.0100 - .0003''}{(1300 - 200) \times c.} = .0000735$$

One pier, 8 inches square, 16¼ inches high and fifteen months old, of face-brick, set in Portland cement mortar, mixed 1 to 2, gives a remarkably uniform curve and a co-efficient of

$$\frac{.0281 - .0064''}{(1500 - 400) \times c.} = 0.0001644$$

One pier, 12 inches square, 23½ inches high, of face-brick, eighteen-and-a-half-months-old-Portland mortar, 1 to 2, gave, up to 1 400 pounds, a co-efficient of..... .0001597

One pier, 16 inches square, 32 inches high, of common brick, same age, etc., up to 700 pounds, gave same..... .0001597

Beyond 700 pounds the common brick compressed the most.

Four piers, twenty-three to twenty-four months old, 8 to 16 inches square, 50 to 100 inches high (see Table No. 6), gave, with Portland mortar, 1 to 2, as follows:

Between limits of 200 and 1 400 pounds—

| | |
|---|---|
| No. 328, of common brick, 16 inches square, 100 inches gauged height, co-efficient..... | .0000667 |
| " 329, of common brick, 12 inches square, 100 inches gauged height, co-efficient..... | .0000658 |
| " 326, of face brick, 12 inches square, 100 inches gauged height, co-efficient..... | .0000722 |
| " 321, of face brick, 8 inches square, 50 inches gauged height, co-efficient..... | .0000652 |

Finally, there were four tests in every particular alike except the mortar.

They were of Bay State bricks, twenty to twenty and one-half months old, height 50 inches. The strongest and the one showing least compression was laid up in Rosendale cement mortar, mixed 1 to 2, and gave a co-efficient, between 300 and 1 000 pounds, of..... .0001012

The next, with Portland cement, 1 to 2, between 400 and 1 000, gave..... .0001083

Rosendale, mixed 1 to 2 sand and 6 lime, between 300 and 800, gave..... .0001800

Portland, 1, 2 and 6, gave between 300 and 900..... .0001639

Collecting the results, we find:

| | Co-efficient, per 100 pounds. | |
|---|---|---|
| One pier, 19½ months, Portland mortar neat, Bay State bricks..... | .0000735 | |
| One pier, 15 months, Portland, 1 to 2 face, Bay State bricks..... | .0001644 | |
| One pier, 18½ months, Portland, 1 to 2 each face and common, about..... | .0001597 | up to 700 |
| One pier, 20 months, Rosendale, 1 to 2 Bay State.. | .0001012 | |
| One pier, 20 " Portland, " " .... | .0001083 | |
| One pier, 20½ months, Portland, 1 cement, 2 lime, 6 sand, Bay State..... | .0001639 | |
| One pier, 20½ months, Rosendale, 1 cement, 2 lime, 6 sand Bay State..... | .0001800 | |
| One pier, 24 months, Portland, 1 cement 2 sand, common..... | .0000667 | |
| One pier, 24 months, Portland, 1 cement 2 sand, common..... | .0000658 | |
| One pier, 23½ months, Portland, 1 cement 2 sand, face..... | .0000722 | |
| One pier, 23½ months, Portland, 1 cement 2 sand, face..... | .0000652 | |

For a refined comparison a much greater number of experiments is requisite. It is evident that there is an increased resistance to compression with increase of age, but it is quite evident also that the figures given are too irregular to be exact.

The only way to make exact determinations will be to build the piers with exactly the same dimensions and thickness of joints and of the same quality of bricks for each mixture of mortar. It is inevitable that as walls are ordinarily built with more or less voids, the compressions must exceed those given in every case.

### Brick Piers in Lime Mortar.

One of the first things to be observed in this Table No. 7 (Plate LXXI) is the very decided loss of strength at rupture of the piers built of Bay State bricks, as compared with the relative strengths in the previous table. This shows very forcibly the important part played by the mortar in any structure.

Taking the piers in the order of age, we have:

1st, two 8-inch piers, 16 inches high, fifteen months old, of which the face brick gives co-efficient..... .0004157
The common brick gives co-efficient..... .0005903
And the average..... .0005048

At eighteen and one-half months the piers are 23 to 24 inches high and 12 inches square.

The face brick gives... .0003208 and .0004312 or an average of .0003760
The common brick gives..... .0007708 and .0005555 " " .0006631
One of the Bay State bricks gives..... .0005950
Average of all at eighteen and one-half months..... .0005260

At nineteen and one-half to twenty months these piers of Bay State bricks, 12 inches square and 72 inches high, give respectively:
.0004417 .0004222 .0002858 and average .0003832

At twenty-three to twenty-four months there are nine piers from 80 to 121 inches high. Of these the face brick give:
.0003131 .0003521 .0002933 and average .0003195

The common brick give:
.0005333 .0008000 and average .0006667

The Bay State brick give:
.0003983 .0005306 .0007500 .0006389 and average .0005794

In every case it will be seen that with lime mortar the face bricks give the least compression, the Bay State appears to be next, and the common brick most. With cement mortar, so far as the experiments go, there is little difference. Referring to thickness of the joints we see those with face bricks are thinnest; and this, together with the greater compression in cubes of lime mortar, would indicate that the increased compression with common bricks occurs largely in the joints, and that the kind of brick has little to do with it. The form of pier, whether hollow or solid, seems to have little effect also.

### Brick Piers with Stone Caps and Bases.

In connection with the foregoing were six piers of North River hard-burned brick, with caps of Kanawha freestone from Virginia. Three 2-inch cubes of the freestone crushed at an average strength of 9 154

pounds per square inch. The piers were laid up with Newark and Rosendale cement, mixed 1 to 2, and were twenty-two months old. The height of the brick work was 16 to 16½ inches, and total height of piers 22 to 22½ inches, the compressions being measured on the whole height.

The curve of the average compressions only has been plotted in Plate LXXII, Table No. 8. Taking the range between 100 and 900 pounds per square inch, gives a co-efficient of .0001469 per 100 pounds.

### Haverstraw Freestone Cubes.

A series of these were tested, giving compressive strength as follows:

| Size. | Number of cubes. | Minimum strength per square inch. | Maximum strength per square inch. | Average strength per square inch. | Size. | Number of cubes. | Minimum strength per square inch. | Average strength per square inch. | Maximum strength per square inch. |
|---|---|---|---|---|---|---|---|---|---|
| Inches. | | Pounds. | Pounds. | Pounds. | Inches | | Pounds. | Pounds. | Pounds. |
| 1 | 2 | 6 959 | 7 107 | 7 033 | 7 | 4 | 5 728 | 6 590 | 6 156 |
| 2 | 4 | 5 590 | 6 718 | 6 004 | 8 | 4 | 6 040 | 6 674 | 6 272 |
| 3 | 4 | 5 795 | 7 202 | 6 245 | 9 | 4 | 5 494 | 7 886 | 6 535 |
| 4 | 4 | 5 340 | 6 341 | 5 962 | 10 | 4 | 5 210 | 8 032 | 6 584 |
| 5 | 4 | 5 302 | 8 052 | 6 467 | 11 | 4 | 6 270 | 6 508 | 6 418 |
| 6 | 4 | 7 048 | 7 719 | 7 355 | 12 | 4 | 5 323 | 5 621 | 5 420 |

It should be said that one of the 10-inch cubes cracked, but did not rupture entirely. Three of the 12-inch cubes also did not rupture, as the limit of strength of the machine was reached. Nevertheless, the averages do not indicate the increase with increase of dimension that has been held to be the law by previous observers.

Prisms of the same stone, two of each size, were tested as follows:

| Size. | Minimum per square inch. | Maximum per square inch. | Average per square inch. |
|---|---|---|---|
| 4 x 4 x 1 inch. | 14 070 | 18 786 | 16 428 |
| 4 x 4 x 2 " | 7 835 | 8 222 | 8 028 |
| 4 x 4 x 3 " | 6 141 | 7 216 | 6 678 |
| 8 x 8 x 2 " | 12 300 | 12 610 | These prisms were not ruptured. |
| 8 x 8 x 3 " | 8 823 | 10 251 | 9 537 |
| 8 x 8 x 4 " | 7 765 | 9 336 | 8 550 |
| 8 x 8 x 5 " | 6 937 | 8 590 | 7 763 |
| 8 x 8 x 6 " | 6 281 | 6 788 | 6 554 |
| 8 x 8 x 7 " | 6 537 | 6 689 | 6 613 |
| From other tables. | | | |
| 8 x 8 x 8 inch. | 6 040 | 6 674 | 6 272 |

The 8 x 8 x 2 inch it is evident would have given at rupture about the same strength as the 4 x 4 x 1 inch. The 8 x 8 x 4 inch were a little stronger than the 4 x 4 x 2 inch; the 8 x 8 x 6 inch a little weaker than the 4 x 4 x 3 inch, and the 8-inch cubes and 4-inch cubes almost identical.

As all these blocks and cubes were carefully selected, so as to be as uniform as possible, the results are certainly interesting.

Compressions were measured on the cubes from 8-inch in size upward, and the curves of the average are plotted on Plate LXXII, Table No. 9. The average of the 20 cubes between 100 and 700 pounds give a co-efficient of

.000175 per 100 pounds.

Beyond this the compression is less, and from about 1 400 to 5 000 pounds it is almost uniform at .0000882.

It will be seen that the first result is very close to the average obtained for cubes of forty-six-months-old Rosendale concrete and mortar. The last is more nearly that of National Portland concrete and mortar.

One reason for the irregular character of the curves for the freestone blocks is that readings were only taken for compression at wide intervals of pressure.

The curve given of the test of a pier of three cubes gives essentially the same result.

In concluding this report of progress we can only say that the results are to be considered as approximations only. The method of averages is undoubtedly the right method to pursue, since every large mass of masonry will present variations throughout its mass, so that the result of pressure on such a mass must be an average between the best and all grades to the poorest.

We hope to be able to obtain more extended tests before making our final report.

## TABLE No. 1.

DYCKERHOFF PORTLAND CEMENT (neat.) Specimens twenty-two months old, buried in sand while hardening. The compressions are reduced to the amount for a foot in length of test. The prisms tested were 12 x 12 inches, there being three of 2 inches, three of 4 inches and three of 8 inches, tested in piers 12, 18 and 24 inches high, respectively, with compressions reduced to that on 1 square inch. (The 11 and 12 inches packed with plaster of paris; the others with brass strips when tested.)

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| Pressures per square inch per foot of length, lbs. | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1 000 | 1 100 | 1 200 | 1 300 | 1 400 | 1 500 | 1 600 | 1 700 | 1 800 | 1 900 | 2 000 | 2 200 | 2 400 | 2 600 | 2 800 | 3 000 | 3 400 | 3 800 | 4 400 | 4 800 | 5 200 | 5 600 | ..... | Rupture. Lbs. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average compression of five 8-inch cubes..... | .00111 | .00216 | .00360 | .00480 | .00603 | .00717 | .00819 | .00933 | .01038 | .01122 | .01197 | .01314 | .01398 | .01467 | .01554 | .01620 | .01701 | .01776 | .01851 | .01920 | .02088 | .02235 | .02352 | .02511 | .02718 | .03003 | .03420 | .04203 | ..... | ..... | ..... | | 4 781 |
| Average of six 9-inch cubes..... | .00123 | 276 | 467 | 607 | 740 | 849 | 967 | 1 064 | 1 164 | 1 267 | 1 351 | 1 438 | 1 515 | 1 573 | 1 684 | 1 767 | 1 851 | 1 940 | 2 007 | 2 080 | 2 220 | 2 347 | 2 511 | 2 640 | 2 797 | 3 103 | 3 489 | 3 890 | ..... | ..... | ..... | | 4 745 |
| Average of six 10-inch cubes..... | .00112 | 320 | 470 | 620 | 722 | 834 | 924 | 1 014 | 1 084 | 1 170 | 1 230 | 1 294 | 1 374 | 1 458 | 1 522 | 1 594 | 1 664 | 1 728 | 1 768 | 1 840 | 1 972 | 2 084 | 2 220 | 2 346 | 2 484 | 2 712 | 2 873 | 3 192 | ..... | ..... | ..... | | 4 761 |
| Average of six 11-inch cubes..... | .00083 | 205 | 308 | 383 | 452 | 527 | 594 | 661 | 725 | 775 | 837 | 903 | 961 | 1 021 | 1 075 | 1 129 | 1 229 | 1 274 | 1 347 | 1 413 | 1 524 | 1 670 | 1 796 | 1 945 | 2 087 | 2 397 | 2 732 | 3 380 | .03698 | .04296 | .05072 | | 5 381 |
| Average of six 12 inch cubes..... | .00080 | 187 | 293 | 360 | 430 | 496 | 555 | 610 | 670 | 723 | 785 | 843 | 910 | 980 | 1 039 | 1 090 | 1 153 | 1 203 | 1 260 | 1 340 | 1 473 | 1 593 | 1 716 | 1 840 | 1 983 | 2 285 | 2 626 | 3 280 | 3 810 | 4 020 | 4 550 | | 5 439 |
| Average of three piers of three prisms each.. | .00110 | 241 | 336 | 453 | 542 | 612 | 683 | 785 | 839 | 911 | 982 | 1 061 | 1 132 | 1 194 | 1 265 | 1 341 | 1 410 | 1 504 | 1 580 | 1 661 | 1 837 | 2 019 | 2 212 | 2 424 | 2 653 | 3 132 | 3 658 | 4 304 | 5 582 | ..... | ..... | | 4 655 |
| Average of twenty-nine cubes and three piers. | .00102 | 241 | 375 | 487 | 585 | 677 | 763 | 847 | 925 | 969 | 1 068 | 1 146 | 1 218 | 1 287 | 1 358 | 1 425 | 1 503 | 1 572 | 1 636 | 1 703 | 1 845 | 1 981 | 2 123 | 2 274 | 2 429 | 2 733 | 3 077 | 3 643 | 4 087 | 4 158 | 4 811 | | 4 828 |

### PORTLAND CEMENT NEAT. SPECIMENS 14½ MONTHS OLD.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average of three 6-inch cubes for 12-in. length | .0043 | .0088 | .0110 | .0118 | .0130 | .0140 | .0150 | .0162 | .0170 | .0180 | .0190 | .0200 | .0210 | .0220 | .0230 | 0.240 | .0250 | .0262 | .0274 | .0286 | .0298 | .0348 | .0382 | 0 418 | .0450 | | | | | | | | |

# TABLE No. 1 A.

DYCKERHOFF'S PORTLAND CEMENT. Individual tests from which averages in Table No. 1 are computed. The upper line indicates pressures per square inch, and the lines below compressions in inches on the sizes given without reduction to uniform length.

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| The Dyckerhoff Lineup | Neat Test | Sizes. | POUNDS. | | | | | | | | | | | | | | | | | | | | | | | | | | | | Register |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1 000 | 1 100 | 1 200 | 1 300 | 1 400 | 1 500 | 1 600 | 1 700 | 1 800 | 1 900 | 2 000 | 2 200 | 2 400 | 2 600 | 2 800 | 3 000 | 3 400 | 3 800 | 4 400 | 4 800 | 5 200 | 5 600 | |
| Inches | | Inches. | ".0013 | ".0026 | ".0039 | ".0051 | ".0062 | ".0067 | ".0080 | ".0092 | ".0101 | ".0108 | ".0110 | ".0119 | ".0127 | ".0131 | ".0139 | ".0145 | ".0105 | ".0157 | ".0163 | ".0170 | ".0181 | ".0193 | ".0200 | ".0213 | ".0230 | ".0255 | ".0287 | ".0350 | ..... | ..... | ..... | ..... | |
| ..... | 49 | 8 | 8 | 11 | 20 | 24 | 34 | 43 | 50 | 57 | 63 | 68 | 72 | 80 | 87 | 91 | 97 | 101 | 107 | 113 | 120 | 125 | 135 | 147 | 157 | 168 | 183 | 202 | 230 | 296 | ..... | ..... | ..... | 4 629 |
| ..... | 50 | 8 | 8 | 11 | 20 | 24 | 34 | 43 | 50 | 57 | 63 | 68 | 72 | 80 | 87 | 91 | 97 | 101 | 107 | 113 | 120 | 125 | 135 | 147 | 157 | 168 | 183 | 202 | 230 | 296 | ..... | ..... | ..... | 4 630 |
| ..... | 51 | 8 | 8 | 17 | 24 | 27 | 38 | 43 | 50 | 57 | 62 | 66 | 70 | 77 | 80 | 84 | 88 | 92 | 98 | 102 | 107 | 110 | 120 | 128 | 135 | 144 | 153 | 174 | 195 | 244 | 260 | ..... | ..... | 4 801 |
| ..... | 52 | 8 | 6 | 14 | 22 | 30 | 38 | 45 | 50 | 57 | 62 | 66 | 70 | 77 | 80 | 88 | 95 | 99 | 105 | 110 | 113 | 115 | 130 | 140 | 150 | 160 | 170 | 192 | 218 | 274 | ..... | ..... | ..... | 4 695 |
| ..... | 53 | 8 | 8 | 13 | 22 | 30 | 40 | 48 | 51 | 59 | 61 | 67 | 77 | 88 | 92 | 98 | 102 | 107 | 110 | 114 | 120 | 128 | 137 | 142 | 152 | 168 | 178 | 210 | 247 | 272 | ..... | ..... | ..... | 4 756 |
| ..... | 54 | 8 | 9 | 23 | 38 | 50 | 62 | 72 | 82 | 92 | 100 | 110 | 114 | 120 | 127 | 133 | 140 | 146 | 151 | 158 | 163 | 170 | 182 | 190 | 200 | 210 | 220 | 240 | 264 | 320 | ..... | ..... | ..... | 4 874 |
| ..... | 55 | 9 | 10 | 28 | 45 | 60 | 73 | 84 | 98 | 108 | 118 | 127 | 136 | 144 | 152 | 160 | 168 | 177 | 184 | 188 | 194 | 200 | 211 | 221 | 230 | 240 | 250 | 270 | 293 | 325 | ..... | ..... | ..... | 4 938 |
| ..... | 56 | 9 | 10 | 28 | 45 | 60 | 73 | 84 | 98 | 108 | 118 | 127 | 136 | 144 | 152 | 160 | 168 | 177 | 184 | 188 | 194 | 200 | 211 | 221 | 230 | 240 | 250 | 270 | 293 | 325 | ..... | ..... | ..... | 4 938 |
| ..... | 57 | 9 | 4 | 10 | 15 | 23 | 30 | 34 | 40 | 45 | 52 | 58 | 62 | 68 | 72 | 77 | 82 | 87 | 91 | 101 | 105 | 110 | 120 | 131 | 143 | 154 | 165 | 184 | 214 | 270 | ..... | ..... | ..... | 4 784 |
| ..... | 58 | 9 | 8 | 16 | 26 | 37 | 44 | 53 | 60 | 67 | 74 | 79 | 85 | 90 | 94 | 97 | 101 | 107 | 112 | 119 | 125 | 130 | 133 | 140 | 152 | 160 | 170 | 179 | 197 | 220 | 252 | ..... | ..... | 4 936 |
| ..... | 59 | 9 | 8 | 12 | 17 | 24 | 34 | 44 | 53 | 60 | 67 | 74 | 81 | 86 | 90 | 100 | 107 | 112 | 119 | 127 | 133 | 140 | 147 | 152 | 159 | 170 | 188 | 199 | 210 | 227 | 239 | 324 | ..... | 4 949 |
| ..... | 60 | 10 | 8 | 18 | 28 | 38 | 53 | 66 | 79 | 90 | 101 | 109 | 113 | 119 | 125 | 132 | 140 | 145 | 151 | 158 | 166 | 170 | 177 | 181 | 192 | 201 | 211 | 223 | 236 | 270 | ..... | ..... | ..... | 3 992 |
| ..... | 61 | 10 | 8 | 10 | 15 | 21 | 24 | 28 | 31 | 40 | 46 | 51 | 54 | 59 | 64 | 71 | 77 | 81 | 85 | 89 | 93 | 98 | 105 | 115 | 124 | 132 | 144 | 158 | 180 | 217 | ..... | ..... | ..... | 4 859 |
| ..... | 62 | 10 | 8 | 8 | 12 | 17 | 23 | 30 | 38 | 46 | 53 | 59 | 64 | 70 | 75 | 80 | 85 | 90 | 95 | 100 | 105 | 110 | 120 | 130 | 140 | 150 | 160 | 170 | 180 | 200 | 220 | 240 | 260 | 4 154 |
| ..... | 63 | 10 | 8 | 42 | 69 | 75 | 87 | 100 | 107 | 115 | 120 | 127 | 131 | 134 | 140 | 148 | 150 | 157 | 160 | 165 | 170 | 175 | 185 | 190 | 200 | 210 | 220 | 240 | 260 | ..... | ..... | ..... | ..... | 4 225 |
| ..... | 64 | 10 | 12 | 36 | 46 | 62 | 75 | 84 | 93 | 103 | 112 | 120 | 127 | 132 | 139 | 147 | 150 | 157 | 162 | 168 | 172 | 180 | 193 | 204 | 215 | 225 | 239 | ..... | ..... | ..... | ..... | ..... | ..... | 4 295 |
| ..... | 65 | 10 | 8 | 20 | 31 | 42 | 52 | 62 | 68 | 75 | 80 | 90 | 95 | 100 | 108 | 116 | 124 | 130 | 136 | 142 | 147 | 151 | 161 | 174 | 190 | 200 | 210 | 242 | 272 | ..... | ..... | ..... | ..... | 4 710 |
| ..... | 66 | 10 | 1 | 20 | 30 | 40 | 46 | 53 | 59 | 65 | 71 | 78 | 84 | 90 | 96 | 102 | 109 | 116 | 123 | 130 | 135 | 140 | 150 | 160 | 170 | 180 | 193 | 220 | 245 | 290 | ..... | ..... | ..... | 4 747 |
| ..... | 67 | 11 | 7 | 21 | 33 | 40 | 47 | 55 | 62 | 69 | 76 | 82 | 90 | 95 | 100 | 105 | 110 | 119 | 126 | 131 | 138 | 144 | 154 | 167 | 180 | 200 | 212 | 238 | 280 | 348 | ..... | ..... | ..... | 4 859 |
| ..... | 68 | 11 | 11 | 20 | 29 | 44 | 56 | 69 | 76 | 87 | 97 | 104 | 110 | 116 | 123 | 130 | 135 | 140 | 145 | 150 | 158 | 165 | 175 | 185 | 200 | 220 | 240 | 260 | 297 | 320 | 412 | ..... | ..... | 5 046 |
| ..... | 68 | 11 | 7 | 17 | 27 | 34 | 40 | 46 | 52 | 59 | 67 | 74 | 77 | 83 | 90 | 97 | 102 | 109 | 113 | 119 | 125 | 130 | 142 | 157 | 169 | 183 | 200 | 230 | 260 | 310 | 370 | 402 | 465 | 4 896 |
| ..... | 69 | 11 | 6 | 10 | 16 | 23 | 30 | 35 | 42 | 49 | 53 | 57 | 62 | 67 | 70 | 77 | 81 | 86 | 91 | 96 | 102 | 108 | 115 | 125 | 140 | 160 | 170 | 195 | 220 | 282 | 313 | 362 | ..... | 5 451 |
| ..... | 70 | 11 | 7 | 15 | 25 | 30 | 36 | 41 | 45 | 50 | 53 | 60 | 65 | 70 | 75 | 80 | 85 | 90 | 100 | 105 | 110 | 115 | 128 | 140 | 150 | 162 | 173 | 200 | 230 | 300 | 330 | 370 | ..... | 4 957 |
| ..... | 71 | 11 | 9 | 20 | 30 | 40 | 48 | 53 | 59 | 67 | 72 | 77 | 82 | 89 | 94 | 100 | 104 | 109 | 114 | 123 | 130 | 135 | 145 | 158 | 168 | 180 | 193 | 220 | 250 | 300 | 338 | 403 | ..... | 5 287 |
| ..... | 72 | 11 | 9 | 20 | 30 | 40 | 48 | 53 | 59 | 67 | 72 | 77 | 82 | 89 | 94 | 100 | 104 | 109 | 114 | 123 | 130 | 135 | 145 | 158 | 168 | 180 | 193 | 220 | 250 | 300 | 338 | 403 | ..... | 5 287 |
| ..... | 73 | 12 | 8 | 16 | 22 | 29 | 36 | 43 | 50 | 56 | 60 | 67 | 69 | 79 | 85 | 92 | 95 | 100 | 107 | 112 | 118 | 127 | 140 | 157 | 170 | 188 | 205 | 235 | 268 | 365 | 460 | ..... | ..... | 4 910 |
| ..... | 74 | 12 | 11 | 20 | 29 | 36 | 43 | 50 | 56 | 60 | 67 | 69 | 79 | 85 | 92 | 95 | 100 | 107 | 112 | 118 | 127 | 140 | 157 | 170 | 188 | 205 | 235 | 268 | 365 | 460 | ..... | ..... | ..... | 4 910 |
| ..... | 75 | 12 | 13 | 26 | 39 | 46 | 54 | 61 | 68 | 77 | 84 | 90 | 96 | 104 | 110 | 115 | 120 | 128 | 135 | 140 | 144 | 152 | 160 | 178 | 190 | 205 | 220 | 240 | 260 | 300 | ..... | ..... | ..... | 5 072 |
| ..... | 76 | 12 | 8 | 20 | 30 | 38 | 42 | 50 | 58 | 62 | 69 | 74 | 79 | 86 | 90 | 100 | 105 | 110 | 118 | 121 | 128 | 137 | 150 | 160 | 170 | 183 | 194 | 218 | 245 | 298 | 340 | 410 | ..... | 5 142 |
| ..... | 75 | 12 | 4 | 14 | 27 | 31 | 38 | 45 | 49 | 54 | 61 | 69 | 75 | 80 | 87 | 94 | 102 | 108 | 111 | 117 | 121 | 129 | 140 | 152 | 162 | 172 | 185 | 213 | 246 | 299 | 350 | 370 | 455 | 5 209 |
| ..... | 76 | 12 | 6 | 17 | 28 | 32 | 40 | 47 | 50 | 55 | 60 | 62 | 68 | 72 | 79 | 86 | 90 | 95 | 102 | 108 | 115 | 120 | 134 | 147 | 160 | 173 | 187 | 214 | 246 | 311 | 355 | 395 | ..... | 5 303 |
| ..... | 77 | 12 | 7 | 20 | 30 | 39 | 48 | 52 | 58 | 62 | 68 | 73 | 80 | 88 | 94 | 101 | 107 | 111 | 119 | 124 | 131 | 138 | 148 | 162 | 178 | 186 | 199 | 230 | 271 | 332 | 400 | ..... | ..... | 5 443 |
| Prisms | 74 | 12 x 12 totals. | 8 | 20 | 32 | 41 | 54 | 63 | 72 | 80 | 89 | 98 | 105 | 114 | 122 | 130 | 139 | 148 | 158 | 170 | 180 | 190 | 211 | 232 | 254 | 276 | 300 | 354 | 410 | ..... | ..... | ..... | ..... | 4 788 |
| | 75 | ..... | 22 | 41 | 59 | 72 | 82 | 91 | 102 | 117 | 127 | 136 | 149 | 160 | 169 | 178 | 189 | 199 | 209 | 220 | 231 | 244 | 270 | 299 | 342 | 370 | 406 | 469 | 579 | 730 | 840 | ..... | ..... | 4 852 |
| | 78 | ..... | 21 | 50 | 77 | 94 | 108 | 120 | 130 | 145 | 156 | 169 | 180 | 195 | 210 | 219 | 231 | 243 | 256 | 269 | 280 | 291 | 320 | 349 | 378 | 409 | 445 | 518 | 603 | 765 | ..... | ..... | ..... | 4 436 |

## TABLE No. 2.

PORTLAND CEMENT, mixed neat, in cylinders 4½ inches diameter, 24½ inches long. Section, $13\frac{36}{100}$ square inches. Compression in inches for 12 inches in length.

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### (1)—Specimen twenty-eight days old.

| Description, etc. | Pressures in Pounds per Square Inch. | | | | | | | | | | | | | | | | | | | | | | | | | | | | | Rupture. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1 000 | 1 100 | 1 200 | 1 300 | 1 400 | 1 500 | 1 600 | 1 700 | 1 800 | 1 900 | 2 000 | 2 100 | 2 200 | 2 300 | 2 400 | 2 500 | 2 600 | 2 700 | 2 800 | 2 900 | 3 000 | |
| Specimen No. 4 | .0020 | .0047 | .0081 | .0111 | .0142 | .0160 | .0184 | .0207 | .0221 | .0247 | .0268 | .0290 | .0305 | .0325 | .0352 | .0380 | .0403 | .0417 | .0444 | 0466 | .0489 | .0506 | .0540 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3 270 pounds. |
| " 3 | .0020 | .0045 | .0078 | .0112 | .0143 | .0178 | .0211 | .0227 | .0253 | .0270 | .0289 | .0302 | .0319 | .0335 | .0363 | .0374 | .0387 | .0406 | .0434 | .0451 | .0469 | .0488 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3 000 " |
| Average | .0020 | .0046 | .0079 | .0112 | .0143 | .0169 | .0198 | .0217 | .0237 | .0259 | .0279 | .0296 | .0312 | .0330 | .0358 | .0377 | .0395 | .0412 | .0439 | .0459 | .0479 | .0497 | .0540 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 3 135 " |

### (2)—Specimen one hundred and four days old.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| One specimen reported July 4, 1887 | .0116 | .0131 | .0147 | .0172 | .0193 | .0217 | .0239 | .0259 | .0279 | .0294 | .0309 | .0319 | .0342 | .0361 | .0372 | .0381 | .0389 | .0412 | .0 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |

### (3)—Specimen six months old.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specimen No. 5 | .0006 | .0013 | .0020 | .0032 | .0045 | .0059 | .0068 | .0076 | .0086 | .0101 | .0111 | .0129 | .0143 | .0158 | .0176 | .0187 | .0203 | .0231 | .0248 | .0257 | .0275 | .0294 | .0307 | .0321 | .0353 | .0379 | .0394 | .0426 | .0454 | .0462 | 3 598 pounds. |

### (4)—Specimen (1 Portland and 2 sand) twenty-eight days old.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specimen No. 12 | .0031 | .0061 | .0135 | .0187 | .0232 | .0244 | .0314 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 050 pounds |

### (5)—Specimen (1 Portland and 3 sand) twenty-eight days old.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specimen No. 15 | .0037 | .0125 | 0.06 | .0286 | 0.360 | .0479 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 600 pounds. |
| Specimen No. 16 | .0057 | .0117 | .0196 | .0278 | .0354 | .0479 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 600 " |
| Average | .0057 | .0121 | .0201 | .0282 | .0357 | .0479 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 600 " |

### (6)—Specimen (1 Portland and 3 sand) six months old.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Specimen No. 17 | .0026 | .0056 | .0083 | .0114 | .0139 | .0154 | .0180 | .0210 | .0237 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 050 pounds. |

## TABLE No. 2 A.

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WHICH HAS NOT BEEN REDUCED TO 100 POUNDS PRESSURE PER SQUARE INCH.

No. 6. Neat Portland cement cylinder, one year old. Length, 24.030 inches. Area, $13\frac{36}{100}$ square inches.

| Load. Pounds. | Compression. Inches. | Load. Pounds. | Compression. Inches. | Load. Pounds. | Compression. Inches. |
|---|---|---|---|---|---|
| 2 000 | 0.0064 | 12 000 | .0510 | 22 000 | .0775 |
| 3 000 | .0170 | 13 000 | .0530 | 23 000 | .0800 |
| 4 000 | .0212 | 14 000 | .0580 | 24 000 | .0822 |
| 5 000 | .0265 | 15 000 | .0605 | 25 000 | .0840 |
| 6 000 | .0320 | 16 000 | .0635 | 26 000 | .0875 |
| 7 000 | .0355 | 17 000 | .0650 | 27 000 | .0895 |
| 8 000 | .0395 | 18 000 | .0685 | 28 000 | .0935 |
| 9 000 | .0435 | 19 000 | .0710 | 29 000 | .0940 |
| 10 000 | .0475 | 20 000 | .0735 | 30 000 | .0950 |
| 11 000 | .0000 | 21 000 | .0750 | 31 000 | .0990 |
| | | | | 32 000 | .1005 |

Crushed at 53 550 pounds.

No. 14. 1 Portland cement, 2 parts sand, one year one day old. Length, 24.500 inches. Area, $13\frac{36}{100}$ square inches.

| Load. Pounds. | Compression. Inches. | Load. Pounds. | Compression. Inches. |
|---|---|---|---|
| 2 000 | .0025 | 11 000 | .0255 |
| 3 000 | .0055 | 12 000 | .0285 |
| 4 000 | .0110 | 13 000 | .0325 |
| 5 000 | .0135 | 14 000 | .0340 |
| 6 000 | .0150 | 15 000 | .0365 |
| 7 000 | .0160 | 16 000 | .0395 |
| 8 000 | .0175 | 17 000 | .0425 |
| 9 000 | .0195 | 18 000 | .0500 |
| 10 000 | .1225 | 19 000 | .0620 crushed. |

No. 19. 1 Portland cement, 3 parts sand, one year sixteen days old. Length, 24.500 inches. Area, $13\frac{36}{100}$ square inches.

| Load. Pounds. | Compression. Inches. | Load. Pounds. | Compression. Inches. |
|---|---|---|---|
| 2 000 | .0110 | 8 000 | .0440 |
| 3 000 | .0175 | 9 000 | .0480 |
| 4 000 | .0230 | 10 000 | .0545 |
| 5 000 | .0290 | 11 000 | .0595 |
| 6 000 | .0340 | 12 000 | .0665 |
| 7 000 | .0380 | 13 000 | .0780 |
| | | 14 000 | crushed. |

## TABLE No. 3.

MORTAR CUBES OF NATIONAL PORTLAND CEMENT (1 cement and 3 sand), forty-six months old. Tested between steel faces packed with plaster of paris.

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| No. of Tests. | Kind. | Pressures per Square Inch in Pounds. | | | | | | | | | | | | | | | | | | | | | | Ultimate Pounds. | Area, Square Inches. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1 000 | 1 100 | 1 200 | 1 300 | 1 400 | 1500 | 1 600 | 1 700 | 1 800 | 1 900 | 2 000 | 2 200 | 2 400 | 2 600 | 2 800 | 3 000 | | |
| | Inches. | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 160 | 8 | .0008 | .0014 | .0020 | .0026 | .0032 | 38 | 43 | 49 | 54 | 59 | 64 | 69 | 74 | 80 | 87 | 94 | 102 | 108 | 115 | 122 | 140 | 161 | ..... | ..... | ..... | 2 586 | 64.96 |
| 161 | 8 | .0033 | 51 | 63 | 70 | 77 | 85 | 93 | 100 | 106 | 113 | 120 | 126 | 132 | 139 | 146 | 153 | 162 | 171 | 180 | 194 | 218 | ..... | ..... | ..... | ..... | 2 370 | 63.28 |
| Average compression on 12 inches..... | | .0030 | .0048 | .0062 | .0072 | .0031 | .0092 | .0102 | .0111 | .0120 | .0128 | .0138 | .0146 | .0154 | .0163 | .0174 | .0185 | .0198 | .0209 | .0221 | .0237 | .0269 | ..... | ..... | ..... | ..... | 2 478 | 64.12 |
| 162 | 12 | .0012 | 18 | 25 | 38 | 45 | 51 | 58 | 67 | 72 | 77 | 82 | 87 | 95 | 103 | 113 | 120 | 129 | 140 | 152 | 167 | 198 | ..... | ..... | ..... | ..... | 2 472 | 144.60 |
| 163 | 12 | .0005 | 14 | 21 | 28 | 34 | 40 | 45 | 54 | 62 | 70 | 77 | 85 | 93 | 104 | 117 | 125 | 135 | 149 | 162 | 178 | 217 | 290 | ..... | ..... | ..... | 2 396 | 144.24 |
| Average..... | | .0009 | .0016 | .0023 | .0033 | .0040 | .0046 | .0052 | .0060 | .0067 | .0074 | .0080 | .0086 | .0094 | .0104 | .0115 | .0123 | .0132 | .0145 | .0157 | .0173 | .0208 | ..... | ..... | ..... | ..... | 2 434 | 144.42 |
| 164 | 16 | .0004 | 11 | 19 | 27 | 34 | 41 | 48 | 56 | 63 | 70 | 76 | 86 | 95 | 103 | 114 | 124 | 133 | 144 | 157 | 172 | 196 | 246 | ..... | ..... | ..... | 2 501 | 259.85 |
| 165 | 16 | .0007 | 18 | 29 | 35 | 42 | 48 | 58 | 67 | 77 | 86 | 95 | 103 | 114 | 125 | 136 | 148 | 161 | 175 | 184 | 203 | 234 | 284 | ..... | ..... | ..... | 2 538 | 257.92 |
| Average compression on 12 inches. ..... | | .0005 | .0011 | .0018 | .0023 | .0029 | .0034 | .0040 | .0047 | .0053 | .0059 | .0065 | .0071 | .0079 | .0086 | .0094 | .0102 | .0110 | .0119 | .0128 | .0141 | .0161 | .0199 | ..... | ..... | ..... | 2 520 | 258.88 |
| Total average compression on 6 cubes | | .0015 | 26 | 34 | 42 | 50 | 57 | 64 | 72 | 80 | 87 | 94 | 101 | 109 | 118 | 127 | 136 | 146 | 158 | 169 | 186 | 213 | 244 | ..... | ..... | ..... | 2 411 | ..... |

CONCRETE CUBES OF NATIONAL PORTLAND CEMENT (1 cement, 3 sand and 6 broken stone), forty-six months old.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 170 | 8 | .0041 | 48 | 56 | 62 | 66 | 69 | 75 | 81 | 84 | 89 | 95 | 100 | 105 | 110 | 116 | 123 | 132 | 140 | 148 | 158 | 177 | 205 | 246 | 300 | 405 | 3 059 | 64 24 |
| 171 | 8 | .0013 | 24 | 32 | 38 | 44 | 51 | 58 | 64 | 71 | 77 | 84 | 92 | 101 | 111 | 121 | 133 | 146 | 162 | 179 | 199 | 227 | 256 | 293 | 360 | 480 | 2 994 | 64.64 |
| Average compression on 12-inch length..... | | .0040 | .0054 | .0066 | .0075 | .0083 | .0090 | .0100 | .0109 | .0117 | .0125 | .0135 | .0144 | .0154 | .0166 | .0178 | .0192 | .0208 | .0226 | .0246 | .0268 | .0303 | .0346 | .0408 | .0495 | .0663 | 3 027 | 64.44 |
| 172 | 12 | .0014 | .0026 | .0033 | .0040 | 48 | 56 | 65 | 72 | 80 | 88 | 99 | 116 | 136 | 160 | 190 | 220 | 250 | 280 | 311 | 344 | 436 | 530 | ..... | ..... | ..... | 2 540 | 144.48 |
| 173 | 12 | .0016 | 31 | 44 | 56 | 64 | 71 | 78 | 85 | 82 | 100 | 107 | 114 | 123 | 131 | 139 | 147 | 158 | 170 | 177 | 190 | 229 | 281 | 339 | 410 | ..... | 2 840 | 144.36 |
| Average 12 inches..... | | .0015 | .0028 | .0033 | .0018 | .0056 | .0063 | .0072 | .0079 | .0086 | .0094 | .0103 | .0115 | 0.130 | .0145 | .0165 | .0184 | .0204 | .0225 | .0244 | .0267 | .0333 | .0400 | ..... | ..... | ..... | 2 690 | 144.42 |
| 174 | 16 | .0011 | 21 | 29 | 36 | 48 | 54 | 62 | 71 | 78 | 87 | 96 | 106 | 118 | 129 | 142 | 151 | 178 | 188 | 206 | 228 | 238 | 352 | 424 | 594 | ..... | 2 880 | 259.37 |
| 175 | 16 | .0014 | 22 | 30 | 40 | 48 | 54 | 60 | 66 | 73 | 82 | 88 | 96 | 108 | 115 | 124 | 138 | 150 | 158 | 168 | 186 | 216 | 272 | 338 | 370 | 466 | 3 077 | 260.01 |
| Average compression on 12 inch length..... | | .0010 | .0015 | .0023 | .0029 | .0036 | .0041 | .0046 | .0052 | .0057 | .0064 | .0069 | .0076 | .0085 | .0092 | .0100 | .0108 | .0123 | .0130 | .0140 | .0155 | .0182 | .0234 | .0255 | .0362 | ..... | 2 979 | 259.69 |
| Total average compression..... | | .0022 | 33 | 42 | 51 | 58 | 65 | 72 | 80 | 87 | 92 | 102 | 112 | 123 | 134 | 148 | 161 | 178 | 194 | 210 | 230 | 273 | 327 | ..... | ..... | ..... | 2 899 | ..... |

## TABLE No. 4.

CUBES OF ROSENDALE CEMENT MORTAR (1½ sand and 1 cement), forty-six months old; tested between steel faces packed with plaster of paris.

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| No. of Test. | Kind. | Pressures in Pounds per Square Inch. | | | | | | | | | | | | | | | | Ultimate Pounds per Square Inch. | Area Square Inches. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1 000 | 1 100 | 1 200 | 1 300 | 1 400 | 1 500 | 1 600 | | |
| | Inches. | | | | | | | | | | | | | | | | | | |
| 120 | 8 | .0017 | .0027 | .0033 | .0040 | .0053 | .0068 | .0077 | .0087 | 0101 | .0117 | .0129 | .0144 | .0163 | .0182 | .0210 | .0245 | 1 640 | 64.64 |
| 121 | 8 | .0022 | .0039 | .0050 | .0065 | .0074 | .0085 | .0098 | .0106 | .0117 | .0129 | .0141 | .0156 | .0169 | .0190 | .0205 | .0247 | 1 852 | 64.80 |
| Average compression on 12 inches | | .0030 | .0049 | .0063 | .0079 | .0096 | .0115 | .0132 | .0145 | .0163 | .0184 | .0202 | .0225 | .0249 | .0279 | .0312 | .0369 | 1 746 | ..... |
| 123 | 12 | .0020 | .0046 | .0056 | .0070 | .0090 | .0110 | .0131 | .0162 | .0190 | .0234 | .0290 | .0360 | .0480 | ..... | ..... | ..... | 1 366 | 144.48 |
| 124 | 16 | .0031 | .0060 | .0080 | .0100 | .0120 | .0140 | .0160 | .0190 | .0228 | .0272 | .0318 | .0388 | ..... | ..... | ..... | ..... | 1 254 | 256.16 |
| 125 | 16 | .0021 | .0050 | .0071 | .0091 | .0111 | .0133 | .0157 | .0184 | .0218 | .0260 | .0320 | .0440 | ..... | ..... | ..... | ..... | 1 240 | 258.08 |
| Average compression on 12 inches | | .0019 | .0041 | .0057 | .0072 | .0087 | .0103 | .0119 | .0139 | .0167 | .0200 | .0239 | .0310 | ..... | ..... | ..... | ..... | 1 247 | ..... |
| Average compression of all | | .0023 | .0043 | .0059 | .0074 | .0091 | 0109 | .0127 | .0146 | .0170 | .0200 | .0254 | .0286 | .0326 | ..... | ..... | ..... | 1 386 | ..... |

CUBES OF ROSENDALE CEMENT MORTAR (1 cement and 3 sand), forty-six months old.

| | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 140 | 8 | .0031 | .0054 | .0074 | .0094 | .0102 | .0147 | .0182 | .0258 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 848 | 64. |
| 141 | 8 | .0037 | .0058 | .0074 | .0094 | .0120 | .0153 | .0182 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 732 | 64.56 |
| Average compression on 12 inches | | .0051 | .0083 | .0111 | .0141 | .0167 | .0225 | .0273 | .0387 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 790 | ..... |
| 142 | 12 | .0020 | .0040 | .0060 | .0080 | .0114 | .0167 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 680 | 144.96 |
| 143 | 12 | .0018 | .0040 | .0060 | .0085 | .0130 | .0192 | .0260 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 695 | 146.17 |
| Average compression on 12 inches | | .0019 | .0040 | .0060 | .0083 | .0122 | .0180 | .0260 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 688 | ..... |
| 144 | 16 | .0027 | .0053 | .0083 | .0113 | .0160 | .0220 | .0330 | ... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 749 | 259.37 |
| 145 | 16 | .0043 | .0075 | .0108 | .0149 | .0190 | .0280 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 687 | 257.12 |
| Average compression on 12 inches | | .0027 | .0048 | .0072 | .0098 | .0131 | .0188 | .0247 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 718 | ..... |
| Average compression of all | | .0032 | .0057 | .0081 | .0108 | .0140 | .0197 | .0260 | .0387 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 711 | ..... |

## TABLE No. 5.

CUBES OF ROSENDALE CEMENT CONCRETE (1 cement, 3 sand and 6 broken stone); forty-six months old.

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| No. of Test. | Kind. | Pressure in Pounds per Square Inch. | | | | | | | | | | | | | Ultimate. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1 000 | 1 100 | 1 200 | 1 300 | 1 400 | |
| | Inches. | | | | | | | | | | | | | | | |
| 150 | 8 | .0071 | .0100 | .0121 | .0149 | .0175 | .0209 | .0266 | .0374 | ..... | ..... | ..... | ..... | ..... | ..... | 879 |
| 151 | 8 | .0028 | .0050 | .0070 | .0090 | .0110 | .0140 | .0177 | .0270 | ..... | ..... | ..... | ..... | ..... | ..... | 844 |
| Average compression on 12 inches..... | | .0075 | .0133 | .0144 | .0180 | .0214 | .0261 | .0333 | .0483 | ..... | ..... | ..... | ..... | ..... | ..... | 862 |
| 152 | 12 | .0017 | .0040 | .0055 | .0077 | .0110 | .0163 | .0328 | .... .. | ..... | ..... | ..... | ..... | ..... | ..... | 775 |
| 153 | 12 | .0018 | .0038 | .0054 | .0074 | .0096 | .0141 | .0280 | ..... | ..... | ..... | ... .... | ..... | ..... | ..... | 757 |
| Average compression on 12 inches... ..... | | .0018 | .0039 | .0055 | .0076 | .0103 | .0152 | .0304 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 766 |
| 154 | 16 | .0032 | .0062 | .0090 | .0120 | .0147 | .0189 | .0242 | .0337 | ..... | ..... | ..... | ..... | ..... | ..... | 858 |
| 155 | 16 | .0025 | .0045 | .0065 | .0085 | .0120 | .0168 | .0270 | .0499 | ..... | ..... | ..... | ..... | ..... | ..... | 828 |
| Average compression on 12 inches..... ..... | | .0022 | .0041 | .0059 | .0077 | .0100 | .0134 | .0192 | .0303 | ..... | ..... | ..... | ..... | ..... | ..... | 843 |
| Average compression of all ..... | | .0038 | .0064 | .0086 | .0111 | .0139 | .0182 | .0274 | .0393 | ..... | ..... | ..... | ..... | ..... | ..... | 824 |

### 1 cement, 2 sand, 3 gravel and 4 broken stone; twenty-two months old.

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 177 | 10 | .0011 | .0030 | .0050 | .0068 | .0088 | .0110 | .0141 | .0182 | .0240 | .0335 | ..... | ..... | ..... | ..... | ..... |
| Average compression on 12 inches..... | | .0013 | .0036 | .0060 | .0082 | .0106 | .0132 | .0169 | .0220 | .0288 | .0402 | ..... | ..... | ..... | ..... | 1 182 |
| 109 | 12 | .0026 | .0050 | .0070 | .0097 | .0126 | .0153 | .0199 | .0253 | .0335 | .0487 | .0680 | ..... | ..... | ..... | 1 113 |
| 113 | 16 | .0029 | .0048 | .0069 | .0089 | .0119 | .0163 | .0238 | .0360 | .0518 | ..... | ..... | ..... | ..... | ..... | ..... |
| Average compression on 12 inches..... | | .0022 | .0036 | .0052 | .0067 | .0089 | .0122 | .0177 | .0270 | .0389 | ..... | ..... | ..... | ..... | ..... | 1 039 |
| 115 | 18 | .0033 | .0062 | .0087 | .0109 | .0144 | .0179 | .0223 | .0303 | .0430 | .0670 | ..... | ..... | ..... | ..... | ..... |
| Average compression on 12 inches..... | | .0022 | .0042 | .0058 | .0073 | .0096 | .0119 | .0149 | .0202 | .0287 | .0447 | ..... | ..... | ..... | ..... | 1 044 |
| Average compression of all ..... | | .0021 | .0041 | .0060 | .0080 | .0104 | .0131 | .0174 | .0236 | .325 | .0445 | .0680 | ..... | ..... | ..... | 1 095 |

### 1 cement, 1½ sand and 6 broken stone; forty-six months old.

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 130 | 8 | .0028 | .0040 | .0050 | .0060 | .0075 | .0089 | .0105 | .0131 | .0165 | .0212 | .0275 | .0359 | .0471 | ..... | 1 352 |
| 131 | 8 | .0050 | .0080 | .0095 | .0110 | .0129 | .0150 | .0171 | .0200 | .0234 | .0273 | .0322 | .0374 | .0441 | .0600 | 1 532 |
| Average compression on 12 inches..... | | .0058 | .0090 | .0109 | .0128 | .0153 | .0180 | .0207 | .0249 | .0300 | .0364 | .0448 | .0550 | .0674 | .0900 | 1 442 |
| 132 | 12 | .0015 | .0030 | .0040 | .0058 | .0071 | .0090 | .0112 | .0142 | .0172 | .0218 | .0268 | .0336 | .0410 | .0560 | 1 503 |
| 133 | 12 | .0027 | .0057 | .0090 | .0110 | .0130 | .0145 | .0164 | .0197 | .0221 | .0260 | .0316 | .0352 | .0417 | .0518 | 1 617 |
| Average compression on 12 inches..... | | .0021 | .0044 | .0065 | .0084 | .0101 | .0118 | .0138 | .0170 | .0197 | .0239 | .0292 | .0344 | .0414 | .0539 | 1 560 |
| 134 | 16 | .0039 | .0057 | .0070 | .0082 | .0093 | .0110 | .0130 | .0162 | .0205 | .0272 | .0375 | .0530 | .0760 | .1011 | 1 466 |
| 135 | 16 | .0020 | .0040 | .0051 | .0070 | .0085 | .0106 | .0130 | .0159 | .0196 | .0259 | .0330 | .0488 | .0622 | .0873 | 1 429 |
| Average compression on 12 inches..... | | .0023 | .0037 | .0046 | .0057 | .0068 | .0081 | .0098 | .0131 | .0151 | .0200 | .0265 | .0382 | .0518 | .0706 | 1 448 |
| Average compression of all.. ..... | | .0034 | .0057 | .0073 | .0089 | .0107 | .0126 | .0148 | .0180 | .0216 | .0268 | .0335 | .0425 | .0535 | .0715 | 1 483 |

# TABLE No. 6.

## Brick Piers Laid in Cement Mortar. Compressions given for 12 inches length in inches.

| No. of Tests | Size of Piers (Nominal) | Total Height | Grouted Height | Area of Sections | No. of Courses | Thickness of Joints. | Age of Specimens | Pressures in Pounds per Square Inch. 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1 000 | 1 100 | 1 200 | 1 300 | 1 400 | 1 500 | 1 600 | 1 700 | 1 800 | 1 900 | 2 000 | 2 200 | 2 400 | 2 600 | 2 800 | 3 000 | 3 200 | 3 600 | Repetitive Tonns per Square Inch | Kind of Brick. | Piers, How Built. | Proportions of Cement Etc. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sq. In. | In. | In. | Sq. In. | | In | Months | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| 12 | 8 | ..... | 16.24 | 57.76 | 7 | $\frac{1}{2}$ | 15 | .0016 | .0030 | .0047 | .0054 | .0083 | .0101 | .0117 | .0141 | .0165 | .0186 | .0207 | .0225 | .0235 | .0258 | .0281 | .0293 | .0307 | .0324 | .0368 | .0578 | .0412 | .0444 | .0488 | .0541 | .0577 | .0609 | .0720 | 3 776 | Face. | Solid. | 1 Portland to 2 sand |
| 328 | 16 | 121 | 100. | 25.6 | 49 | $\frac{1}{4}$ | 24 | .0001 | 6 | 15 | 23 | 33 | 34 | 39 | 43 | 50 | 58 | 67 | 77 | 88 | 100 | 113 | 130 | 149 | 172 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 887 | Common. | " | " " " |
| 329 | 12 | 120 | 100. | 138.06 | 48 | $\frac{1}{4}$ | 24 | .0001 | 7 | 16 | 25 | 34 | 42 | 49 | 56 | 64 | 70 | 80 | 89 | 97 | 111 | 127 | 139 | 154 | 171 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2 003 | " | " | " " " |
| 326 | 12 | 119.8 | 100. | 132.25 | 51 | $\frac{5}{16}$ | 23½ | .0001 | 6 | 11 | 16 | 21 | 26 | 32 | 38 | 45 | 52 | 60 | 70 | 79 | 88 | 100 | 116 | 125 | 140 | 154 | 177 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2 253 | Face. | " | " " " |
| 321 | 8 | 80 | 50. | 57.76 | 35 | $\frac{3}{8}$ | 23 | .0001 | 6 | 12 | 19 | 27 | 34 | 41 | 59 | 66 | 76 | 85 | 94 | 102 | 111 | 126 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2 249 | " | " | " " " |
| Average at 23 to 24 months | | | | | | | | .0001 | 6 | 13 | 21 | 29 | 34 | 40 | 49 | 56 | 64 | 73 | 82 | 91 | 102 | 116 | 128 | 143 | 161 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | " " " |
| 286 | 12 | 23.50 | 23.50 | 132.25 | 16 | $\frac{1}{2}$ | 18½ | .0008 | 20 | 30 | 46 | 69 | 96 | 117 | 148 | 162 | 182 | 200 | 227 | 236 | 250 | 276 | 303 | 311 | 321 | 340 | 347 | 372 | 405 | 447 | 473 | 500 | 540 | 719 | 3 670 | Face. | Solid. | |
| 287 | 16 | ..... | 31 85 | 256. | 13 | $\frac{1}{2}$ | 18½ | .0005 | 12 | 25 | 39 | 56 | 83 | 117 | 183 | 212 | 241 | 280 | 330 | 350 | 372 | 396 | 433 | 450 | 470 | 492 | 578 | 658 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | Common. | " | " " " |
| Average at 18½ months | | | | | | | | .0007 | 16 | 28 | 43 | 63 | 90 | 117 | 166 | 187 | 212 | 240 | 279 | 293 | 312 | 336 | 368 | 381 | 396 | 416 | 463 | 515 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | " " " |
| 301 | 12 | 73⅝ | 50. | 144. | 30 | $\frac{5}{16}$ | 20½ | .0002 | 10 | 22 | 42 | 61 | 82 | 108 | 130 | 151 | 177 | 209 | 239 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 646 | Bay State. | Solid. | 1 Rosendale, 2 lime, 6 sand. |
| 293 | 12 | 72⅜ | 50. | 144. | 30 | $\frac{5}{16}$ | 20 | 0002 | 8 | 13 | 26 | 37 | 48 | 62 | 72 | 84 | 98 | 113 | 127 | 144 | 168 | 183 | 204 | 223 | 257 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 972 | " " | " | " 2 sand. |
| 294 | 12 | 72⅜ | 50. | 144. | 29 | $\frac{5}{16}$ | 20 | .0001 | 6 | 14 | 23 | 34 | 47 | 60 | 72 | 86 | 101 | 120 | 134 | 150 | 175 | 192 | 212 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 792 | " | " | 1 Portland, 2 sand. |
| 300 | 12 | 73⅛ | 50. | 144. | 30 | $\frac{5}{16}$ | 20½ | .0001 | 10 | 26 | 45 | 64 | 84 | 103 | 125 | 144 | 165 | 193 | 215 | 240 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 411 | " | " | " 2 lime, 6 sand. |
| 290 | 12 | 72 | 50. | 144 | 30 | $\frac{5}{16}$ | 19½ | .0000 | 3 | 11 | 19 | 29 | 38 | 47 | 55 | 62 | 72 | 84 | 94 | 100 | 120 | 129 | 138 | 150 | 162 | 173 | 186 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2 375 | " | " | Neat Portland. |

### Terra Cotta Cylinder.

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ..... | 48⅛ | 30 | ..... | ..... | ..... | ..... | .0003 | 11 | 21 | 33 | 44 | 63 | 72 | 96 | Fluted terra cotta cylinder of 8 segments, each 5½ inches high, joined by cement, 15½ outside diameter, with 5$\frac{2}{10}$ inches core. | 881 | Compressive strength of segments was 3 432 pounds. |

## TABLE No. 7.

BRICK PIERS LAID IN LIME MORTAR (1 lime and 3 sand). Compressions given for 12 inches length in inches.



| No. of Test | Size of Pier. (Nominal.) | Total Height. | Gauged Height. | Area of Sections. | No. of Courses. | Thickness of Joints. | Age of Specimen. | Pressures in Pounds per Square Inch. | | | | | | | | | | | | | | | | | | Ruptured in Pounds per Square Inch. | Kinds of Brick. | Pier, How Built. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1 000 | 1 100 | 1 200 | 1 300 | 1 400 | 1 500 | 1 600 | 1 700 | 1 800 | 1 900 | 2 000 | 2 200 | 2 400 | | | |
| | Sq. in. | In. | In | Sq. in. | | In. | Months | | | | | | | | | | | | | | | | | | | | | | | | |
| 11 | 8 | ..... | 16 | 57 | 7 | ..... | 15 | .0051 | .0098 | .0149 | .0195 | .0246 | .0289 | .0329 | .0403 | .0433 | .0500 | .0537 | .0616 | .0664 | .0713 | .0766 | .0861 | .0933 | .0955 | .1003 | .1090 | .1249 | .1335 | 2 520 | Face. | Solid. |
| 10 | 8 | ..... | 16.48 | 60.8 | 7 | ..... | 15 | .0150 | 244 | 322 | 395 | 462 | 528 | 582 | 646 | 712 | 766 | 824 | 926 | 989 | .1072 | .1122 | .1165 | .1217 | .1272 | .1342 | .1421 | ..... | ..... | 2 440 | Common. | " |
| Average at 15 months | | | | | | | | .0101 | .0171 | 236 | 295 | 354 | 409 | 456 | 525 | 583 | 633 | 691 | 771 | 827 | 893 | 944 | 1013 | .1075 | .1114 | .1173 | .1256 | ..... | ..... | ..... | ..... |
| 283 | 12 | ..... | 23 05 | 132.25 | 10 | ..... | 18½ | .0021 | 57 | 94 | 131 | 168 | 213 | 252 | 324 | 381 | 438 | 522 | 641 | 719 | 771 | 834 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 947 | Face. | " |
| 284 | 12 | ..... | 22.04 | 113.76 | 10 | ..... | 18½ | .0052 | 109 | 158 | 206 | 259 | 307 | 374 | 429 | 518 | 562 | 624 | 682 | 736 | 798 | 863 | 926 | 986 | ..... | ..... | ..... | ..... | ..... | ..... | 1 990 | " | Hollow, with interior space 4½ x 4½ in. |
| 281 | 12 | ..... | 23.90 | 138.06 | 10 | ..... | 18½ | .0050 | 138 | 226 | 316 | 404 | 498 | 605 | 673 | 763 | 856 | 932 | 979 | .1082 | .1148 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2 130 | Common. | Solid. |
| 282 | 12 | ..... | 23 90 | 119.68 | 10 | ..... | 18½ | .0015 | 60 | 130 | 198 | 260 | 344 | 439 | 540 | 636 | 742 | 838 | 931 | .1038 | .1123 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 2 050 | " | Hollow. (Space 4½ x 4½ in.) |
| 285 | 12 | ..... | 24.10 | 146.41 | 10 | ..... | 18½ | .0053 | 193 | 200 | 274 | 339 | 410 | 505 | 546 | 632 | 736 | 826 | 933 | .1071 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 570 | Bay State. | Solid. |
| Average at 18½ months | | | | | | | | .0038 | 99 | 162 | 225 | 286 | 354 | 435 | 502 | 586 | 667 | 748 | 831 | 929 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 288 | 12 | 72½ | 50 | 144. | 30 | ⅛ | 19½ | .0010 | 51 | 100 | 152 | 207 | 263 | 332 | 382 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 133 | Bay State. | " |
| 291 | 12 | 72¼ | 50 | 144. | 30 | ⅛ | 20 | .0007 | 22 | 60 | 110 | 158 | 212 | 281 | 326 | 386 | 448 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 331 | " | " |
| 292 | 12 | 73 | 50 | 156¾ | 19 On edge. | ⅛ | 20 | .0005 | 27 | 60 | 94 | 129 | 161 | 197 | 233 | 267 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 211 | " | " |
| Average at 19½ to 20 months | | | | | | | | .0007 | 33 | 73 | 118 | 165 | 212 | 270 | 313 | 329 | 448 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |
| 320 | 8 | 80 | 50 | 57.76 | 35 | ⅛ | 23 | .0003 | 12 | 31 | 66 | 105 | 146 | 175 | 212 | 253 | 294 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 877 | Face. | " |
| 325 | 12 | 94½ | 80 | 144 | 39 | ⅛ | 23½ | .0005 | 26 | 71 | 116 | 163 | 213 | 265 | 329 | 381 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 174 | Bay State. | " |
| 327 | 12 | 119.6 | 100 | 144. | 49 | ⅛ | 23½ | .0004 | 20 | 64 | 113 | 168 | 255 | 329 | 410 | 498 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 924 | " | " |
| 330 | 12 | 120½ | 100 | 115½ | 50 | ¼ | 24 | .0002 | 17 | 52 | 113 | 175 | 242 | 301 | 372 | 438 | 502 | 565 | 638 | 700 | 788 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 587 | Common. | Hollow. (Space 4¼ x 4¼ in.) |
| 331 | 12 | 117⅜ | 100 | 138.06 | 49 | ¼ | 24 | .0004 | 24 | 109 | 216 | 356 | 550 | 650 | 739 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 118 | " | Solid. |
| 332 | 12 | 119⅞ | 100 | 132.25 | 52 | ¼ to ⅜ | 24 | .0002 | 13 | 38 | 81 | 131 | 182 | 240 | 295 | 350 | 398 | 457 | 510 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 1 511 | Face. | " |
| 334 | 12 | 119⅞ | 100 | 115.44 | 52 | ¼ | 24 | .0001 | 17 | 51 | 88 | 122 | 159 | 193 | 232 | 272 | 314 | 355 | 398 | 410 | 490 | 530 | 579 | 600 | ..... | ..... | ..... | ..... | ..... | ..... | 1 807 | " | Hollow. (Space 4 1/10 x 4 1/10 in.) |
| 333 | 12 x 16 | 120½ | 100 | 192. | 49 | ¼ | 24 | .0000 | 24 | 103 | 202 | 306 | 384 | 534 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 773 | Bay State. | Solid. |
| 335 | 8 x 12 | 120½ | 100 | 96. | 49 | ¼ | 24 | .0000 | 19 | 93 | 162 | 249 | 332 | 413 | 512 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | 940 | " | " |
| Average at 23 to 24 months | | | | | | | | .0002 | 19 | 68 | 129 | 199 | 274 | 344 | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... |

## TABLE No. 8.

BRICK PIERS AND BASE WITH BLUESTONE CAP.—Compressions in inches for 12 inches in length.

Caps, 2.75 to 3.10 inches thick; bases, 2.75 to 4.15 inches thick; bricks, 8 x 3¾ x 2¼ inches, set in Newark Company's Rosendale cement (1 cement to 2 sand); twenty-two months old; piers packed with brass strips where needed.

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| No. of Test. | Kind. | Pressures in Pounds per Square Inch. | | | | | | | | | | | | | | | | | | | Ultimate. | Area in Square Inches. | Height. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | 1 000 | 1 100 | 1 200 | 1 300 | 1 400 | 1 500 | 1 600 | 1 700 | 1 800 | 1 900 | 2 000 | | | Inch. |
| 78 | 12 x 12 | .0018 | 38 | 56 | 72 | 85 | 94 | 115 | 131 | 140 | 163 | 184 | 201 | 223 | 248 | 278 | 307 | 342 | 394 | 454 | ..... | 2 021 | 144.0 | 22.42 |
| 79 | 12 x 12 | .0019 | 41 | 63 | 83 | 101 | 120 | 138 | 158 | 179 | 195 | 217 | 238 | 263 | 291 | 317 | 391 | ..... | ..... | ..... | ..... | 1 821 | 142 8 | 22 08 |
| 80 | 12 x 12 | .0029 | 53 | 71 | 89 | 104 | 118 | 135 | 153 | 169 | 197 | 222 | 243 | 271 | 304 | 342 | 384 | 444 | ..... | ..... | ..... | 1 805 | 144.0 | 22.58 |
| 81 | 12 x 12 | .0016 | 32 | 46 | 59 | 71 | 87 | 102 | 117 | 133 | 150 | 173 | 191 | 210 | 234 | 268 | 291 | 339 | 394 | ..... | ..... | 1 944 | 144 0 | 22.50 |
| 82 | 12 x 12 | .0034 | 66 | 86 | 110 | 129 | 148 | 166 | 187 | 211 | 232 | 260 | 283 | 310 | 347 | 396 | 434 | ..... | ..... | ..... | ..... | 1 736 | 144.0 | 23.22 |
| 83 | 12 x 12 | .0033 | 42 | 58 | 65 | 89 | 106 | 124 | 143 | 163 | 187 | 214 | 241 | 272 | 308 | 367 | 416 | 507 | ..... | ..... | ..... | 1 780 | 141.0 | 21.98 |
| Average .... | | .0025 | 45 | 63 | 80 | 96 | 112 | 130 | 148 | 166 | 187 | 212 | 233 | 258 | 289 | 328 | 370 | ..... | ..... | ..... | ..... | 1 851 | ..... | ..... |

# TABLE No. 9.

CUBES OF HAVERSTRAW FREESTONE, set in plaster of paris and tested between steel cushions. Compressions in inches for 12 inches in length.

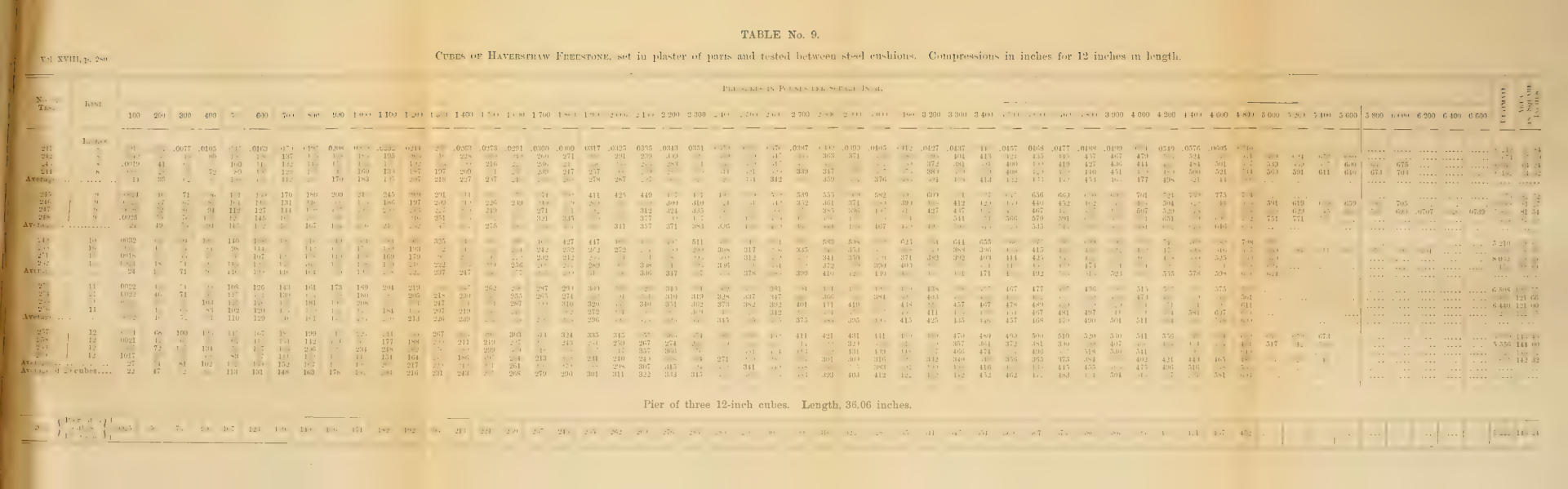

PLATE LXVIII.
TRANS AM SOC CIV ENGRS
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REPORT ON CEMENT.

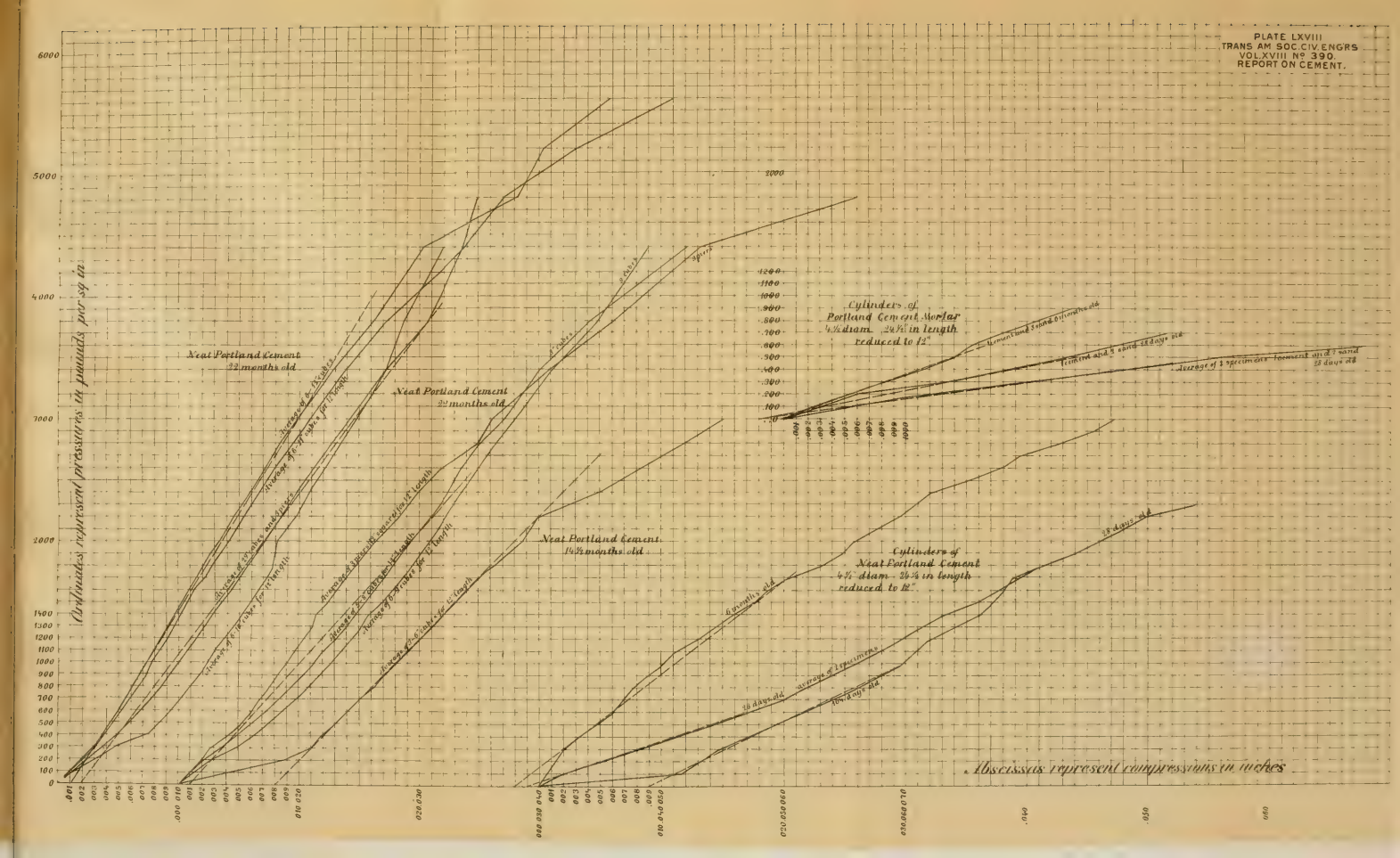
Ordinates represent pressures in pounds per sq in
Abscissas represent compressions in inches
Neat Portland Cement
22 months old
Average of 6 cylinders
Average of 6 cylinders, each 24 hours
Average of 6 cylinders, each 7 days
Average of 6 cylinders, each 28 days
Average of 6 cylinders, each 3 months
Average of 6 cylinders, each 12 months
Neat Portland Cement
22 months old
Neat Portland Cement
14½ months old
Cylinders of
Portland Cement Mortar
4½ diam 24½ in length
reduced to 12"
Average of 3 specimens 1 month old
Average of 3 specimens 3 months old
Average of 3 specimens 6 months old
Average of 3 specimens 1 year old
Average of 3 specimens 2 years old
Average of 3 specimens 3 years old
Cylinders of
Neat Portland Cement
4½ diam 24¾ in length
reduced to 12"
7 days old
28 days old
3 months old
1 year old
2 years old
3 years old

PLATE LXIX
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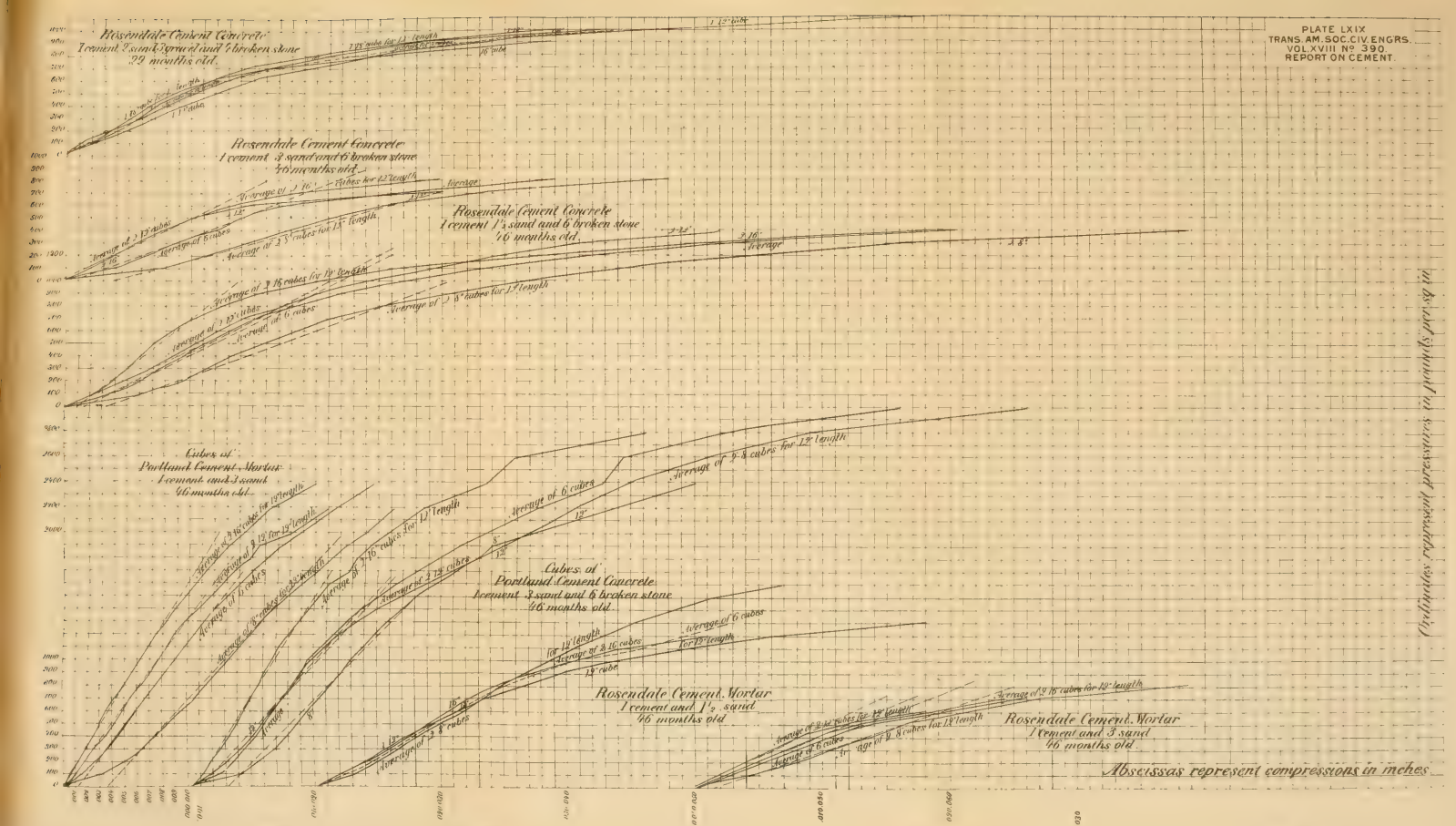
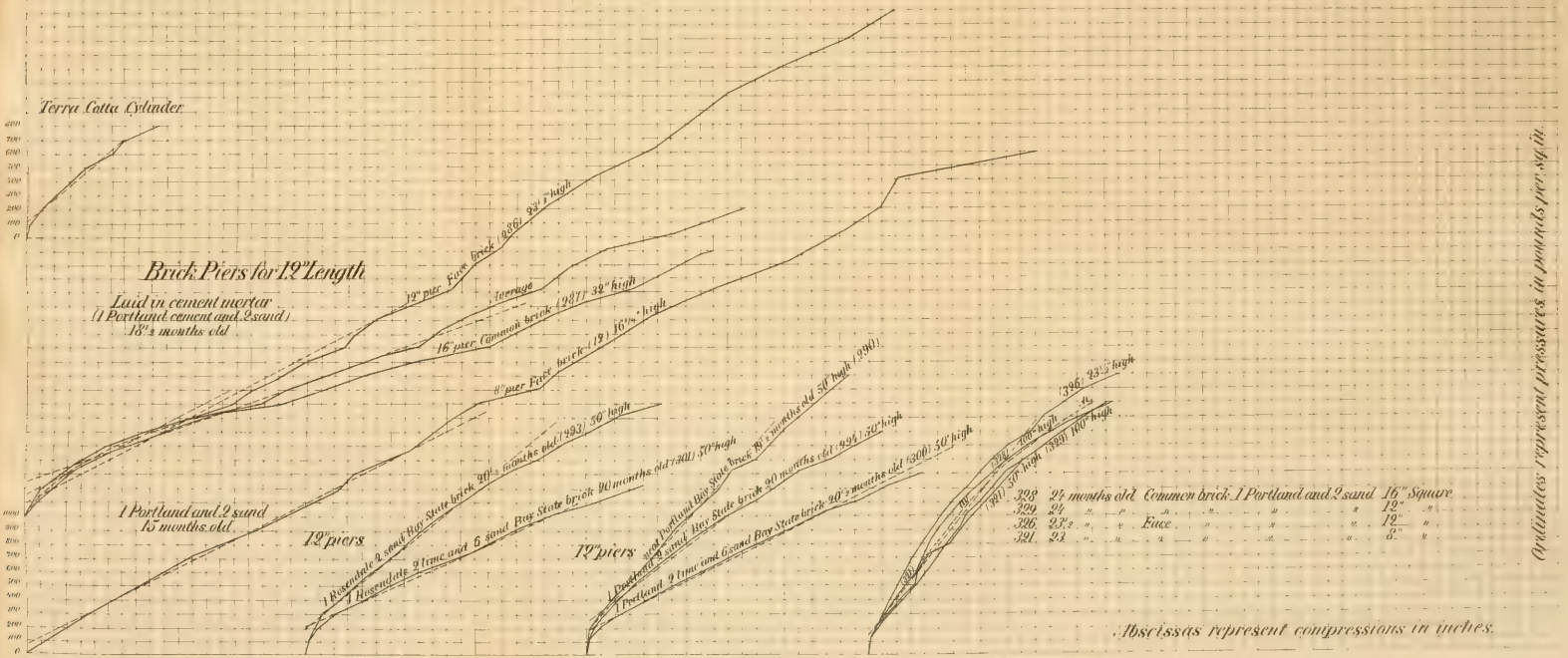

Rosendale Cement Concrete
1 cement 2 sand 3 gravel and 7 broken stone
22 months old.
Rosendale Cement Concrete
1 cement 3 sand and 6 broken stone
46 months old.
Rosendale Cement Concrete
1 cement 1½ sand and 6 broken stone
46 months old.
Cubes of
Portland Cement Mortar
1 cement and 3 sand
46 months old.
Cubes of
Portland Cement Concrete
1 cement 3 sand and 6 broken stone
46 months old.
Rosendale Cement Mortar
1 cement and 1½ sand
46 months old
Rosendale Cement Mortar
1 cement and 3 sand
46 months old
Abscissas represent compressions in inches.

Published separately pursuant to Journals, Jan. 19, 1889.


Terra Cotta Cylinder
Brick Piers for 12" Length
Laid in cement mortar
(1 Portland cement and 2 sand)
15 months old
12" per Face brick (386) 93½ high
Average
16" per Common brick (287) 32" high
8" per Face brick (9) 16½" high
1 Portland and 2 sand
15 months old
12" piers
1 Rosendale 2 sand Bay State brick 20½ months old (493) 50" high
1 Rosendale 2 lime and 5 sand Bay State brick 90 months old (301) 50" high
1 Portland 2 sand Bay State brick 90 months old (494) 50" high
1 Portland 2 lime and 6 sand Bay State brick 20½ months old (300) 50" high
(321) 50" high (393) 100" high
(396) 23½ high
(394) 100" high
328 2½ months old Common brick 1 Portland and 2 sand 16" Square
329 2½ " " " " " " " 12" "
326 2½ " " Face " " " " 12" "
321 23 " " " " " " " 8" "
Abscissas represent compressions in inches.
Ordinates represent pressures in pounds per sq.in.

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TRANS AM SOC CIV ENGRS
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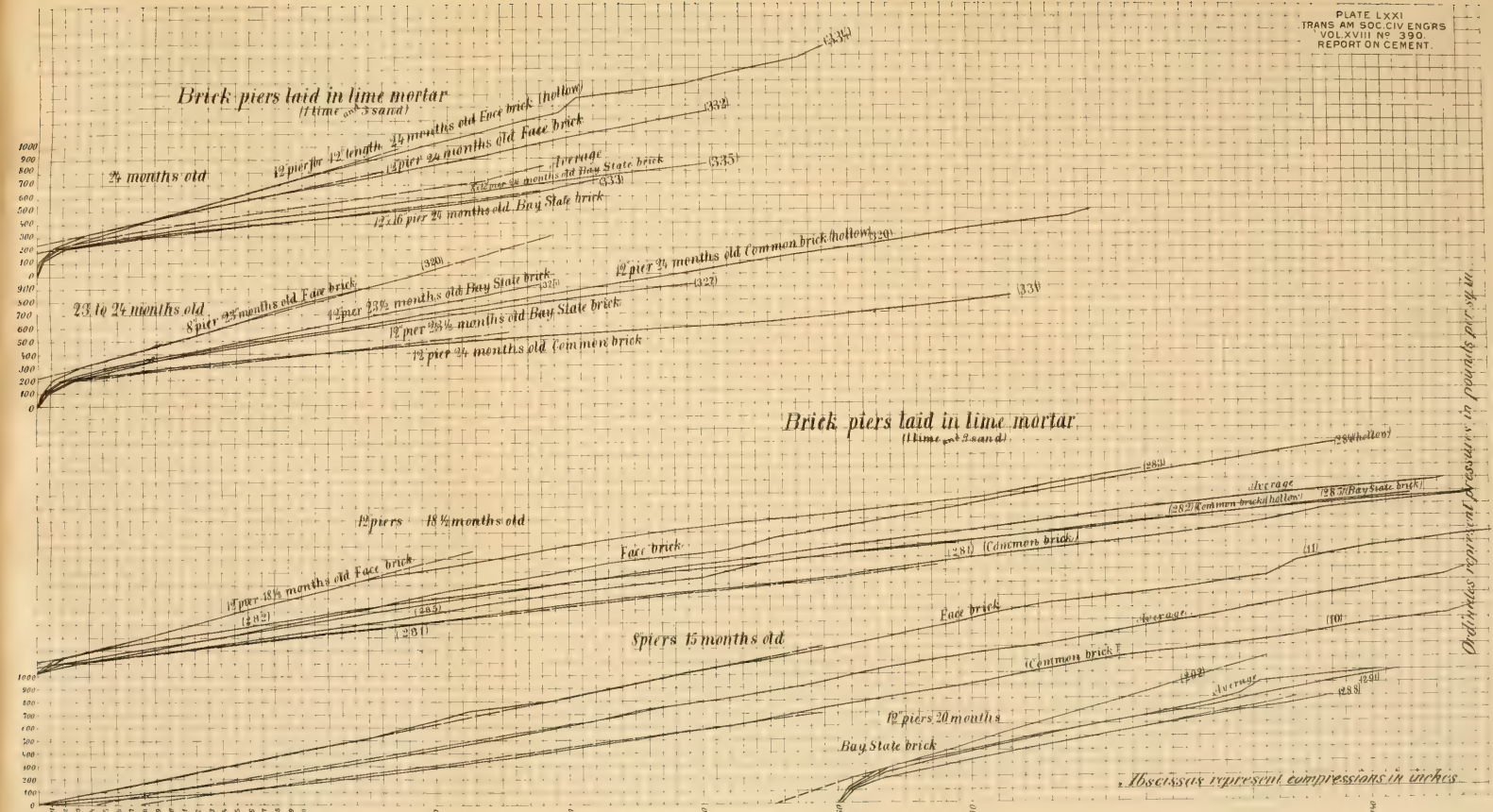

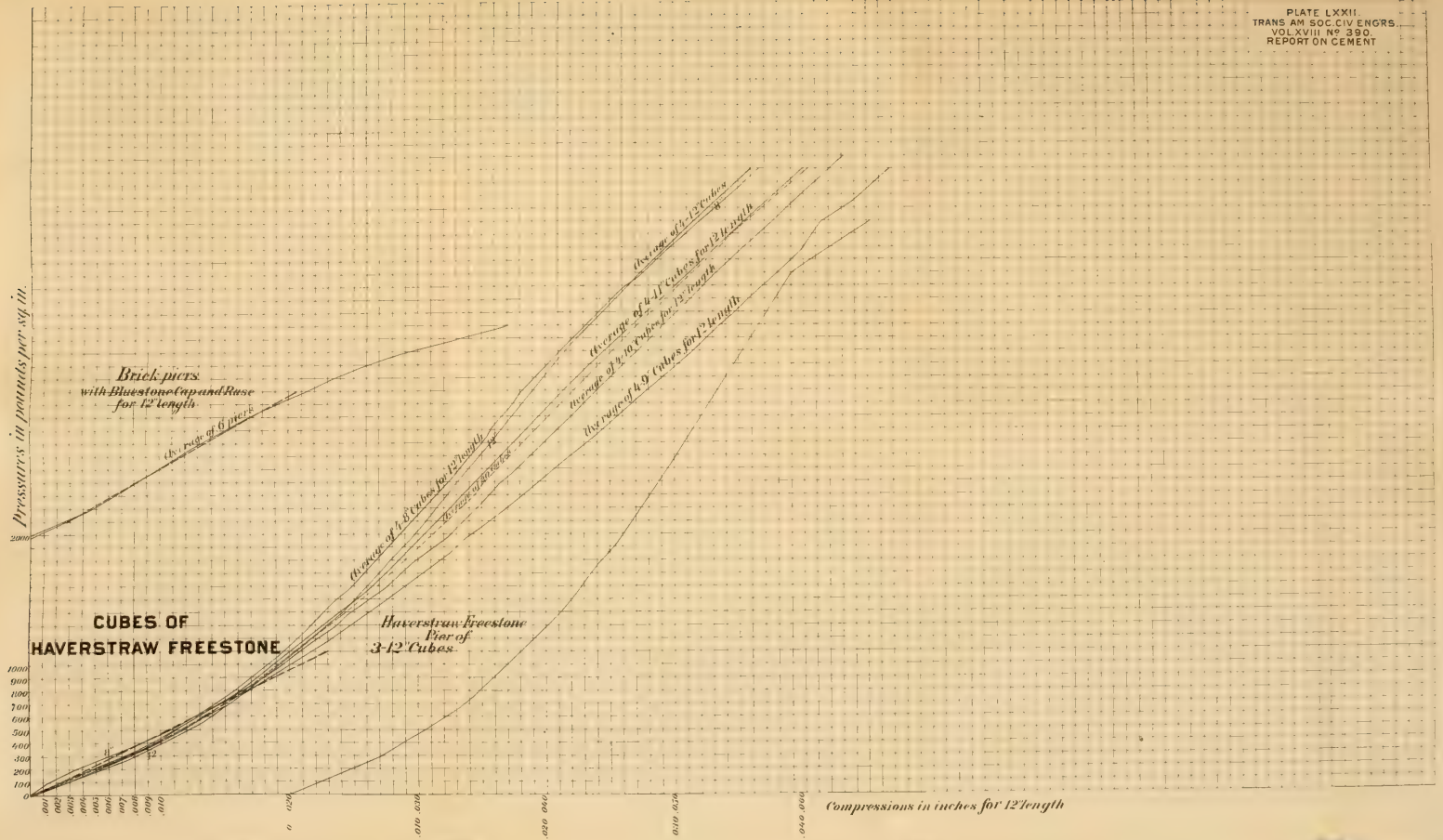
Pressures in pounds per sq. in.
Brick piers with Bluestone Cap and Base for 12" length
Av. rate of 6 piers
CUBES OF HAVERSTRAW FREESTONE
Haverstraw Freestone Pier of 3-12" Cubes
Average of 4-12" Cubes
Average of 4-11" Cubes for 12" length
Average of 4-10" Cubes for 12" length
Av. rate of 4-9" Cubes for 12" length
Compressions in inches for 12" length

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INSTITUTED 1852.

TRANSACTIONS.

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# THE MANUFACTURE OF BRICK.

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## THE BRICK INDUSTRY ABOUT NEW YORK CITY.

By CALVIN TOMKINS, Assoc. Am. Soc. C. E.
READ MARCH 16TH, 1887.

The Dutchmen who came to New York brought their bricks with them, and it was not till the financial depression which succeeded the Revolutionary War had passed away that the manufacture of brick was established in this vicinity.

Previous to the present century what few bricks were used for the better class of structures continued to be imported at ballast rates from Holland and England. The freight being nominal, the cost would not be so great as might at first be supposed.

These old bricks are of a yellow-red color, smaller, and in particular, thinner than the average brick now used. When fractured, they indicate the presence of an excess of loamy clay and an insufficiency of sand. They generally appear to be under-burnt. As a rule they are in a good state of preservation, which is largely to be attributed to the custom of painting the exposed surfaces. Some of the bricks in the Treason Hill House, near Haverstraw, are stamped Haverstraw, 1772, and it is probable that the industry was irregularly carried on along the Hudson and North Jersey shores for some time previous to 1815, when James Wood left Sing Sing, where he then made brick, and started a brick-yard at Haverstraw. It is to the enterprise of this man that the manufacture of brick owes its first impetus.

In 1826 he introduced the custom of mixing anthracite dust with the clay before molding. As a result of this improvement, the time necessary to burn a kiln of brick was reduced from a period of two weeks or more to one week; the quantity of cord wood required was cut down three-fourths; and the expense, total, of a burn reduced to two-fifths of the former cost. The green bricks being sufficiently porous to admit air to the particles of coal dust, cause the brick to burn equally throughout; and the wood now burnt under the arches is simply that which is necessary to raise the temperature of the brick, and maintain it at a point where the coal will ignite. Mr. Wood secured a patent on his process, but was not able to resist the combined pressure of other manufacturers who adopted his methods, and who at last began to realize a fair return from the industry. The quality of bricks improved while prices fell off, and a growing demand brought about an increased output, which still continues to run up the totals of the yearly product.

In 1849 the first steam molding machines were introduced by Ver Valen of Haverstraw. These early machines were very defective, but improvements were soon made, and the old-time process of molding by hand has long since been discarded. With the exception of the two changes just noticed, the methods of brick-making have practically remained unchanged in this vicinity.

Bricks which come to the New York market are classed as follows, according to locality, viz.:

*Haverstraws*, which include all bricks made on the Hudson below the Highlands.

*Up Rivers*, or those made on the Hudson above the Highlands.

*Jerseys*, which are manufactured along the north coast of New Jersey.

*Hackensacks*, which are manufactured on the Hackensack River near Hackensack, N. J.

*Long Islands*, which are manufactured along the north shore of Long Island.

*Staten Islands*, which are manufactured along the Freshkills of Staten Island.

Front bricks are sold here from Philadelphia, Trenton and Baltimore, and a second-class front is made on the Hudson at Verplanks and Croton. These last are known as Croton fronts.

Fire-bricks and the hollow bricks used for fire-proofing buildings are made in the district about Woodbridge, N. J., and on Staten Island.

Buff-colored bricks, such as were used in the construction of the Cotton Exchange and *Post* Buildings of this city, are made of clays deposited about Amboy and Sayerville, N. J., and Glens Falls, N. Y., which are comparatively free from the oxides of iron.

Excellent enameled bricks of various colors are made at Croton.

Clay is defined as a silicate of alumina containing an excess of free silica. It is primarily caused by the action of carbonic acid and water present in the atmosphere, which combine with alkalies of the feldspar in granitic rocks. Weathering accelerates the decomposition; the soluble products, consisting of alkaline carbonates, being washed away, leaving the clay. The clay about New York is generally superimposed on rock or gravel, and is, as a rule, overlaid with sand, which is as necessary as clay to the manufacture of good brick.

The north shore of Long Island, from Glen Cove to Greenport, is girt with meadows and headlands of drift. These deposits of clay and sand are worked at or near Locust Valley, Cold Spring, Huntington, Greenlawn and Northport.

The Long Island clays are variegated in color, and the bricks made from them are of excellent quality when proper care is taken. Few, however, come to the New York market, and then only when other bricks are scarce. The output is not large, and is principally absorbed by the towns of Long Island and those located along the Connecticut shore.

Bricks of good quality have recently been made at Fisher's Island, and many of them have been used in the construction of the new aqueduct.

Few bricks are made along the shore of Connecticut, but a few miles back from the coast good bricks are made and shipped by rail to neighboring towns.

Three or four small yards are located on the Freshkills at Staten Island. Their output is small, of inferior quality, and gray in color.

They are only shipped in the winter season when ice interferes with shipments from other points.

The bricks made along the coast of New Jersey about Keyport, South River, and Perth Amboy, are of very irregular character. The trade divides them into four classes, known respectively as

*Dark hards*, which have been highly burned, are very dense, and of a dark red color.

*Light hards*, which have not been subjected to such an intense heat in the kilns as the former class, and which are lighter in color, but still hard and durable.

*Grays*, which may be considered as under-burnt bricks, or bricks made from clay not containing sufficient ferruginous matter to afford a proper color.

*Sulphur bricks*, which are made from clay containing an excess of pyrites, and which are more or less swelled, warped, or spotted by the oxidation of this compound during ignition.

Nearly all of the bricks known as Jerseys show evidences of the presence of sulphate of iron in the clays of which they are made, and this is the most serious objection that can be raised against them. Unless oxidation of the pyrites is completed during the process of burning it will continue in the presence of the air, and is likely to impair the strength of the brick by expansion, resulting in unbalanced stresses.

The bluish-black spots and vitrified blotches which affect the surface more or less of all these bricks, are due to the same cause, and for this reason they are generally unfitted for wall work, where appearance is a consideration.

As a rule, Jersey bricks are rough and not so well made as the Hackensacks and those made in the upper and lower Hudson valleys. The lack of plenty of good accessible sand in the vicinity of these brick-yards occasions the use of a larger proportion of clay to sand than is generally employed elsewhere, and causes the brick to shrink and sometimes to warp slightly. However shrinkage is made up for by increasing the sizes of the moulds, and these bricks are fully as large, if not larger, than the average brick. Many of these yards produce a strong, tough brick.

Great improvements have been made in the process of manufacture, and the industry is probably more rationally pursued in this section than elsewhere.

The principal change affected has been the use of coal under the arches in place of wood.

The best Jersey bricks are frequently preferred on account of their greater density.

A brick is now being manufactured by a new process near Keyport, which shows no sulphur spots, which appears to be regularly made, and in which very little sand is used. It is not as yet on the market.

Fifteen years ago few, if any, brick were made at Hackensack. Now a number of large yards are engaged in the business. The bricks are a good uniform red color and contain more sand than Jerseys. While they are a fine appearing brick, they frequently lack strength, and unless handled carefully are liable to considerable breakage. They are well liked by the city builders, and the facilities for manufacture are about to be largely increased.

Bricks are made at Mechanicsville and other points along the canal above Albany, but rarely come to this market. Like those made about Greenbush and Albany they are rough and generally not over strong.

At Coeymans, Castleton, and Trust Camp a few bricks are made, and they are fair in quality, but inclined to brittleness, which is the distinguishing characteristic of all up river brick.

Athens, Hudson, and Coxsackie bricks are of a gray-red color; as a rule not well made, nor very strong.

The Hudson bricks generally burn a dirty yellow-red color, and have a somewhat mottled appearance.

Glasco bricks are of better quality, but of a gray tinge, and not carefully made.

The Catskill bricks are probably the strongest which come to the New York market. They are in good demand, but the manufacturers are not sufficiently careful, and regard quantity rather than quality. If carefully burnt the color is a good red, but through carelessness the right shade is not generally attained, and the bricks as a consequence burn a light salmon-red.

Good sand is scarce at Catskill, and a large portion of what is used is scowed up from below the Highlands. As a natural consequence less sand is used with the clay. This is one of the reasons for the superior strength of the bricks. The same cause contributes to the density, and consequent strength, of certain of the Jersey bricks. The bricks shrink in burning however; are somewhat smaller than an average brick, and cannot, even with care, be made as squarely as if more sand should be used. The main cause of the strength of these bricks is said to lie in the clay, and probably this is the true explanation.

Bricks from Saugerties, Port Ewen, and Kingston are generally well made and of good shape. This is especially true of those coming from the latter place. The prevailing color is gray, excepting the Port Ewen bricks, which are a good red.

There is an excess of quicksand in most of these clays, and the resulting bricks are quite brittle. The yards along Newburgh Bay put out the best up river bricks. In fact for the last few years they have approximated both in price and quality to Haverstraws. The color is a good solid red. The bricks are well made and considered to be nearly as strong as those made further down the river.

The Haverstraw influence has made itself felt here more than else-

where, and many of the yards are managed by men who have migrated from the lower bay, and who have been accustomed to the more careful manipulation of clay. These bricks are known as New Windsors, made two miles below Newburgh; Mud-hole brick, made two miles above Newburgh; Fishkills, Low Points, and Dutchess Junction brick.

In discussing the quality of brick as related to locality, what is stated must be received in a very general sense, since local advantages or disadvantages are treated in very different ways by the manufacturer. Good bricks are often made by a careful man out of bad material, while the reverse proposition is equally true. In fact bricks are sold on the name of the maker rather than on the locality of the yard.

Good sand is scarce above the Highlands, and many of the up river yards are supplied in whole or in part with sand from below. To the lack of this material is attributed the general brittleness which distinguishes with few exceptions up river brick. It must be added, however, that carelessness is also a primary cause. Brick manufacture can be conducted for only six months of the year, and the demand comes with a rush which sweeps up bad as well as good brick in ordinary years, and in specially prosperous years cannot find a sufficiency. When this is recalled, it will be remarked how great the tendency must be towards quantity rather than quality. Besides the demand for the best brick is not great. The speculative building interest which constructs most of the city will use what the law allows if it cannot do better on the sly. All the pale brick and lammies are supposed to go to Brooklyn, where the law is more considerate. Architects as a rule specify "best Haverstraw brick," but are liable to be lax in their inspection, and receive whatever comes. Engineers generally introduce the same clause, and if they insist will obtain what is called for.

Of all the common brick other than fronts which come to New York City, those made along Haverstraw Bay, from the Race down to Sing Sing, are considered the best, and the highest prices are realized for them.

Poor bricks as well as good bricks are made through carelessness along this reach of the river; but the fact remains that the average brick made here is superior to brick made at other points. This is due principally to two causes:

*First.*—The tempering sand in this section is abundant and of the best quality, and the clay is also said to be superior.

*Second.*—The experience of brick-makers counts for more, as the industry has been of longer standing.

Generally speaking these bricks possess a finer finish and are more regular in form than those made elsewhere. The color is usually a good uniform red, and they are stronger than other bricks.

I shall now proceed to describe the brick industry as it exists along the shores of Haverstraw Bay. With few exceptions the method followed

here is adhered to by the brick-makers in the localities I have already mentioned.

Deposits of clay in this section, when adjacent to navigable water, possess a high value. They can seldom be bought, as the owners prefer to receive the royalties for the clay used per thousand bricks made. The bank-owners are in most instances retired brick-makers; well-to-do men who prefer the assured income of a landlord's position to the anxiety and hard work incident to the proper management of a brick yard.

The brick plant, consisting of machinery, docks, sheds, etc., goes with the use of clay and sand, and all are included under one royalty. The lessee also binds himself to make not less than a certain quantity per annum.

Royalties along Haverstraw Bay average fully one dollar per thousand bricks made. Some yards laboring under natural disadvantages, such as long hauls, inferior or no plant, wet clay pits, etc., range as low as fifty cents, and some specially favored yards bring the owners one dollar and fifty cents per thousand. Up river yards, with the exception of those along Newburgh Bay, command lower rents. These latter bring in nearly the same returns that the Haverstraw yards do, while the limit of others is an approximation to the interest which will maintain the plant. Staten Island, Long Island, Jersey, and many of the up river yards are worked as a rule at first hands, the margin not yet being sufficient to admit of two profits.

To illustrate the value of brick clay *in situ*, I would instance the experience of the North River Construction Company in acquiring the right of way for the West Shore Railroad back of Haverstraw. The line here runs through clay land situated over a mile back from the river, and yet the company found it necessary to pay, for what they expected to obtain at farm land valuations by the acre, four cents per cubic yard for sand and clay, over a strip sixty-six feet wide at the surface and extending down to high water mark, with a slope of 1 to 2.

The Haverstraw blue clay is generally overlaid with a thin layer of yellow clay, which is mixed with the blue before moulding, and which assists in giving to the resulting brick a good color.

Frequently curious stone-like concretions, termed clay dogs, occur in the upper strata of clay, and while they are not found here in sufficient quantities to prove seriously detrimental, they are sometimes objectionable. They consist of a small mass of clay impregnated with carbonate of lime, which is supposed to be conducted downward in solution following the roots of trees and plants. This saturation causes the surrounding clay to harden, and if introduced into the brick results in lime.

After stripping the sand, the stiff clay is cut out in benches and carted to the yard. In some instances before going into the machines the clay and sand are tempered in what is termed a circular pit, about

thirty feet diameter and two and one-half feet depth. A six-foot vertical wheel revolves on a shaft which travels around the pit and gradually works inward from the periphery.

Bricks made by this method are more homogenous, and consequently stronger, but the expense of manufacture is greater. The general method followed is to dump the clay, sand and coal-dust in alternate layers (two of each) into a square sod pit 16 x 12 x 4 feet. A bushel of coal-dust is allowed for each thousand bricks, which, roughly speaking, average from one-third to one-half sand. Sand however is not added by any constant rule, as the clays themselves contain more or less.

In both instances the pits are situated close to the moulding machines, and the mud is shoveled directly into the hopper. Considerable skill is required on the part of the shovelers in the sod pits to introduce the correct proportions of clay and sand.

The use of sand in bricks is analogous to its use in mortar. Clay in burning will shrink considerably, but when well tempered with sand throughout the mass, continuous shrinkage is broken up into separate shrinkages between the grains of sand, consequently the original mould form is not impaired, and the internal stresses are equitably distributed.

The sand itself remains inert, or only at the highest temperatures submits to incipient vitrifaction and fuses slightly at the surfaces with the clay. Its purpose is that of a diluent used to secure economy, strength, and symmetry. The mud from the pits is forced downwards through the body of the machine by a screw movement into a form of six moulds. This form is shoved out automatically and an empty form inserted by hand. The bottoms of the moulds are not tight, but admit air through narrow slits, so that the green brick can be easily dumped. A very fine moulding sand is dusted over the inside of the moulds after occasionally thrusting them into water, and before inserting them into the machine. This gives a finish to the surfaces of the brick, and also assists their rejection from the moulds. Coloring matter is sometimes inserted in this sand. After removal from the machine the tops of the moulds are struck off by hand, the forms placed upon light trucks, wheeled to the drying yards and dumped.

The drying yard consists of a plain surface, faced with a few inches of clay at the beginning of each season and kept well rolled. Occasionally the yard is covered with a succession of low, peaked roofs, supported by rows of posts, each side of the roof being divided into five feet battens, which can be closed or opened on trunnions like ordinary window-blinds, according to the state of the weather. Gutters carry off the rain. The advantages of a covered yard are self-evident, and yet few are constructed on account of the expense. Later in the day the bricks are turned on their sides and spatted to make their edges straight. In the afternoon they are gathered up and packed in rows three to four feet high and one brick wide. Saddles, consisting of two

12-inch boards nailed together at the edges, are placed over the bricks as a protection against the weather, and battens can be laid against the sides if bad weather is apprehended. They remain in hack from one and a half to four days, as atmospheric conditions may favor drying. They are then wheeled to the kiln and set up for burning. In the course of a season many green bricks are damaged by rain, and the loss is sometimes serious.

The kilns are usually built entirely of the green brick from the hacks, and are set up under long roughly built sheds at the end of the yards, and almost always run parallel to and within a few feet of the river. The two lines of heavy roof posts support in part the sides of the kilns, and to prevent accidents from the swelling of the brick during ignition the opposite posts are clamped together by bands of iron. On this account the kilns are usually referred to as clamp kilns.

Three hundred thousand to one million bricks are built edgewise into the kiln, allowing thirty-five to forty thousand to an arch. The kilns are about fifty bricks high, and thirty-six feet wide at the base, built with a very slight batter.

The bricks are set crossing each other, three on three, allowing vents ¼ to ⅜-inch for the heat to pass through. At intervals of about three feet at the base of the kilns, and extending through them from side to side, small pointed arch openings are built thirty inches high and sixteen inches span. Cord wood for burning is here introduced, and is supported on a brick hearth. The ends of the kilns are cushioned with moulding sand held in place by battens. By this means more of the heat is retained, and the sand is dried properly for dusting the moulds.

The sides of the kiln are daubed with clay, and slow fires started up under the arches. Drying off or water smoking, as it is termed, is carried on from thirty-six to thirty-eight hours. The arches on one side are then closed, and the fires driven diagonally through the kiln at a temperature sufficient to produce a white heat in the lower inside tiers of brick, which is gradually carried up to the top and opposite side. Then the process is reversed, with similar results.

The arches on both sides of the kiln are now fired, and this process of cross burning is carried to its conclusion. The whole operation takes about a week, after which the kiln is allowed to cool down, requiring another week. This part of the manufacture is the most critical and skillful of all the stages, and is intrusted to men of experience, who command high wages. It is a rule of thumb process throughout. The kiln, fifty bricks high, will sink from two inches to six inches in burning. A gauge along the side measures this settlement, and gives valuable information to the burner as to what progress has been made. The burner must regulate the intensity and direction of his fires entirely by the drafts at the arch openings. Barometric changes, changes of temperature and the wind have to be taken into consideration and guarded against.

As a matter of course bad burns occasionally occur; the arch brick are over-burnt and the outside brick under-burnt. This constant loss is a great drain on the industry, and also tends to deteriorate the quality, as it is the general custom to work the greater part of these poorer bricks off by inserting them among the good ones. Brick-makers have estimated that by the present process one-twentieth of the kiln turns out pale brick and one-twelfth arch brick. About five to six cords of wood, at an average cost of six dollars per cord, are required to burn forty thousand bricks.

The chemistry of burning may be roughly described as follows:

At a temperature of 100 degrees C., the water held in mechanical suspension is driven off. That held in chemical combination is then expelled at a temperature below red heat. At about red heat the decomposition of carbonates, if present, and the combustion of organic matter takes place. This is followed by a more intimate combination between the bases (iron, alumina, lime, and the alkalies) and the silica. This last process is known as vitrifaction.

If carried to a completion glass would be the result, but in practice vitrifaction is only carried to an incipient stage. The fusibility of the brick is increased by the presence of iron and the alkalies, and in a general way, lime, alumina and silica tend to diminish the fusibility.

The power of clay to recombine with water is, according to Bischoff, permanently lost at a temperature of 660 degrees Fahr.

In connection with the chemistry of brick-making, I would remark that the generally accepted explanations of the efflorescence which frequently appears on the surfaces of brick walls is that it is due to the presence of sulphates, nitrates, and chlorides of magnesia, potash and soda in the bricks or mortar. These are highly soluble compounds, and in wet weather are brought to the surface in solution and there precipitated.

# BRICK MANUFACTURE NEAR CHICAGO.

By D. V. Purington.

Read April 18th, 1888.

In complying with your request for a brief description of the methods in use by the Purington-Kimbell Brick Company for making brick, I wish it distinctly understood that the Company makes no claim that these methods are original, or that they are exclusively their own.

There are several other firms who have adopted the same process, some of whom have more expensive plants, and some of whose yards excel ours in convenience of arrangement. I do feel, however, that I have the right to lay claim to being the pioneer in the use of the Chambers stiff mud machine, which has achieved so complete a success in Chicago. The first machine of this kind was erected by Messrs. Purington & Kimbell, the predecessors of this Company, in the early spring of 1882.

It was placed on a yard that the previous year had operated seven horse-power machines of the kind so generally used along the Hudson River. The clay used was dredged from the Chicago River, and one season clearly demonstrated the impracticability of its use on the Chambers machine. Taken as it was from the water, it required at least a year to dry out sufficiently to be available. The experiment was carried far enough, however, to prove that the hard, tenacious, blue clay which underlies our whole city, could be advantageously worked in its normal condition.

In June, 1882, Messrs. Purington & Kimbell secured another location on the banks of the Illinois and Michigan Canal, and located a second machine, designing to use the clay that had been dredged from the canal twenty-five years before. From its long exposure this clay was peculiarly adapted to the machine, and in the fall of 1882, the first machine, with engine, boilers, dryers, etc., was removed to the canal bank.

These two machines, one with dryer and one with out-door drying, made in 1883, 1884 and 1885, forty-six millions of brick. The maximum was ten millions on the machine with dryer and six millions five hundred thousand on the out-door yard. In the spring of 1883, this Company was incorporated and purchased the interest of Messrs. Purington & Kimbell, and, the clay becoming exhausted, purchased 47 acres of ground on the Rock Island Railroad, 14 miles from Chicago, and in the spring of 1886 erected thereon the works you have asked me to de-

scribe. The wisdom of going so far away from the city and endeavoring to compete has been clearly shown by the fact that the Company are able to deliver brick by rail to Chicago, and by teams to the building at a less cost than they had been able to do it from the yard in the city limits. The railroad company named the new station "Purington," and hereafter in this letter the new location will be known by that name. The clay here differs somewhat from that at or immediately around Chicago. It is much freer from limestone pebbles, and less of the consistency of india rubber, but is very hard, although slightly granulated.

For the first six months it was obtained by the use of pick and spade. It was found impossible to secure eleven men who could mine and load sufficient clay for forty-five thousand brick in a day of ten hours. As the season advanced, and the bank became dryer and harder, dynamite was freely used to assist in "getting a fall of the bank." In July of that year our bills for dynamite amounted to $85, and our average day's work less than we had made since the introduction of the Chambers, and we came to the conclusion that unless some more economical plan was devised, the Company would go the way of the dynamite.

Correspondence was opened with the manufacturers of steam shovels, and a contract made for one. At this point we committed the blunder that has been the bane of so many brick-makers, viz.: of trying to economize by getting machinery too light for its work. The expert who knew just what we needed, insisted that a No. 2 was ample for our wants. Four weeks of worry and bother decided that we had saved at the spigot and lost at the bung, and we were glad to make the best terms we could in exchanging for a larger one. This one was built with a dipper intended to hold 1½ yards, but, on our suggestion, was changed for a 1-cubic yard size. It requires 2 yards of clay, measured as dug, in the cars, to make one thousand brick.

Our shovel will easily dig enough for two hundred and twenty-five thousand brick in ten hours, inclusive of time consumed in moving, etc.

The dipper cuts from 4 to 5 inches in depth, 3 feet in width and 25 feet from bottom to top. This cut will ordinarily fill the dipper with clay, thoroughly mixed, cut in small pieces, and the two yards are taken from the bank and placed in the car in less than one minute's time. The cars are drawn from the shovel to the turn-table, a distance varying from 100 to 700 feet, by horses. Until the present year, our cars have been of the style in general use by railroad contractors, a box holding 2 yards placed on a half circle for a dumping rocker. The entire weight and strain comes upon one point, a line drawn lengthwise through the center of the car. I have found in dumping from the steam shovel, or in drawing these cars over an uneven track, that there was a great liability to breakage. I have now adopted the plan of dumping or tipping the track. The frame-work of my track is made of oak, 4 inches by

6 inches in size. Under this frame is placed a shaft 3 inches in diameter, with three bearings in each length of 16 feet, with the car fastened securely to the track. The operation of emptying the clay from the car is simple, and it is almost impossible to break anything. Under the old system (Cockrell) one man was kept steadily employed repairing cars. The cars are drawn up by a hoistway from the turn-table to the machine house.

The contents of the cars are dumped upon a platform, below which stand two Cockrell pulverizers, one for each brick machine. These pulverizers have never—and probably will never come into general use, for the reason that so few clays can be successfully worked by them. With us they seem to fill the bill exactly. The object of the machine is to tear the clay to pieces, by a sort of whittling, its chips resembling in shape and condition those obtained in sharpening a lead pencil. It consists of a hollow vertical cylinder, at the bottom of which is a revolving horizontal disk, moved by a vertical shaft, connected above to the motive power. In the horizontal disk are set a number of knives, in the same manner as the knives of a plane, but with the cutting edges up. The slots in the disk in which the knives are set are also similar to the openings in a reversed plane. Underneath the machine is a belt conveyor. The top of the cylinder is on the level of the floor on which the clay is dumped.

It is the work of two men to shovel the clay from the floor into the cylinder when the disk is revolving two hundred and fifty times in a minute. The idea is to plane the clay in chips, pass it through the slots, and deposit it on the belt or elevator. It is then carried to the hopper over the brick machine. Around this hopper is a platform on which stands a boy, whose place it is to see that the hopper does not clog, and to add what water is necessary.

The brick machine is in charge of one man, who should be a tolerably good machinist, as well as a careful man of good judgment. The bricks leave the machine on the flat, but are immediately edged automatically. Three boys, from fourteen to sixteen years of age, take the brick from the belt and put them upon an iron car, each car containing five hundred and forty bricks. These cars are then taken by a man and run into the tunnels to dry.

There is nothing new or original about these tunnels, unless it is their length, 94 feet, and the use of an exhaust fan instead of a stack to remove the steam. Eleven tunnels, with a 30-inch fan for each two tunnels, will thoroughly dry fifty thousand brick in twenty-four hours. I am a decided advocate of artificial circulation to bring artificial drying to a point anywhere near perfection.

These tunnels should be filled before any are drawn out, and when a car is drawn it should be replaced by another. The grade is 1 inch to 10 feet. One man is sufficient to keep the fires in good condition, to draw out the brick when dry, remove ashes, etc.

In front of the storage tracks is a wide-guage track with a transfer car, on which the cars of dried brick are run to any portion of the 1 100 feet of kiln shed. Four men, who still retain the designation of brick wheelers, take the product of each machine to two setters. Our average for each machine in 1887 was forty-four thousand three hundred for each ten hours. I have given in detail the men actually engaged in making the brick and setting them in the kiln. As there are so many men whose work is divided on the whole four of our machines, I submit herewith the list and classification of our employees at Purington. I refrain from giving the wages paid, as that would vary in different localities and really does not enter into this comparison.

4 machine men.
4 " boys on platform.
8 men at pulverizer.
2 " hoisting machines.
1 engineer on steam shovel.
1 fireman "
1 craneman "
6 men in clay bank.
12 boys loading cars, handling cars, etc., with green brick.
4 men to put cars in dryer.
4 " fire dryers and take cars out.
4 " " " " at night.
24 " setting and wheeling.
1 engineer.
2 firemen.
1 carpenter.
1 blacksmith.
3 laborers.

83 Total.

Thus it will be seen that eighty-three men and boys make, dry and set in the kiln an average of one hundred and seventy-seven thousand two hundred brick per day.

From 1883 to 1885, with one machine used with dryers and one with out-door drying, our average was one hundred and sixty-seven days for the latter and two hundred and fifty-four for the former. The cost of brick dried artificially is less than those dried out of doors. The longer the season and the steadier the job the better the grade of men who will seek it. I have refrained from entering into a detailed description of the Chambers machine, for the reason that it is too well known to brick-makers to need it. This Company pays every two weeks, and during its existence has never missed a pay day and never had a strike. Since its location at Purington, no intoxicated man has ever been seen on or about its premises. Its relations with its employees are never strained;

and, while neither the Company nor men make any claims to foresight or sagacity peculiar to themselves, they do claim to have that perfection of an organization known as a union of the employer and employed. During the past year the Company erected a building 28x40 feet for the exclusive use of the men. They furnish heat and light, and the only restrictions placed upon the men are, that it shall be closed at 10 P.M., shall be kept clean and orderly, and that no intoxicating liquors shall ever be taken into it.

From a portion of the above it may be inferred that the executive officers of the Company are fanatics on the temperance question. This is not the case, but they are fanatical on the intemperance question.

The question of burning brick with crude oil has engaged the serious consideration of this Company for a year past, although it is only three months since their first experiments were made. The developments thus far in this new branch of a science, so all important to the brick-maker, are too crude and new to warrant any extended remarks. All who have tried it agree that as a fuel it comes nearer perfection than any other they have tried or known of, except it be natural gas.

All who have looked into the matter at all agree that hot oil, hot steam and hot air are necessary. No two agree, as yet, on the necessary quantities of either or the proper method of mixing them. I have now burned six kilns or about two million one hundred thousand brick. Thus far we have not had a bad kiln, and my experience justifies me in saying that I feel much more certain of a good burn than I ever did with wood and coal. The cost of burning with us is 35 per cent. less with oil than with wood and coal, and with large kilns the cost of labor is much less; two men will easily handle a kiln of twenty arches. No cold air is admitted and the checked, cracked arch bricks resulting from such admission are avoided. It is a promising field for experiment, and within six months, if we meet with no drawbacks, I hope to be able to write and talk more intelligently in regard to it.

In reply to questions Mr. Purington said: "My drying tunnels are 36 inches wide by 48 inches in height, and the average amount of coke used during the past two years in drying brick in twenty-four hours has been one ton to fifteen thousand brick. This coke costs me f. o. b. cars at Purington, $5 55 per ton. The expense is about equal to anthracite coal at $6 25; but I prefer the coke for the reason that the gas in the coal is more destructive to the iron cars. I should, perhaps, have mentioned that I have a steam dryer that, with a few changes, I think will accomplish better results than the hot-air dryers. Of this, however, I prefer to write when I am satisfied what it will do. In a general way, let me say there are many clays that can be successfully dried with a steam heat that cannot be with heated air passed over or through a heavy fire. While I regret very much that my time is too fully occu-

pied to write as intelligently or exhaustively as the subject deserves, I desire to congratulate the progressive clay worker that a body like yours deems our avocation of sufficient importance to give it so much attention. I have given to it seventeen years of the best of my life, and feel that I, with others who have tried so hard to place this industry in its proper place among the mechanical arts, have reason to congratulate ourselves that we are in the future to have the active co-operation of your Society."

# SLATE BRICKS.

By José R. Villalon, Jun. Am. Soc. C. E.

Read April 18th, 1888.

The manufacture of slate bricks is carried on throughout the year by the American Brick and Tile Company, at Phillipsburg, N. J. This company started work in 1886, and since then they have kept always busy, and it has been necessary to enlarge and improve its plant.

The material used in making the bricks is the rubbish from slate quarries, though all kinds of slate may not be suitable, as experiments have been made with slates from Massachusetts, which were not entirely satisfactory. The rubbish used in this manufactory is of two different kinds of slate from the quarries of the Old Bangor Slate Company, at Bangor Pa., whose chemical composition is as follows, from analysis furnished by the Old Bangor Slate Company.

| | Clear. | Ribbon. |
|---|---|---|
| Silica | 56.78 | 56.15 |
| Alumina | 17.38 | 13.90 |
| Lime | 4.14 | 5.17 |
| Magnesia | 3.15 | 2.81 |
| Iron peroxide | 6.50 | 7.46 |
| Sulphur | 0.89 | 2.22 |
| Phosphoric acid | 0.133 | 0.13 |
| Water and carbonic acid | 7.60 | 10.47 |
| Alkalies and organic matter | 3.427 | 1.69 |
| | 100.000 | 100.000 |

This shows an equivalent of iron of 4.54 and 5.22 per cent. respectivly.

The plant used until the end of the year 1887 had a capacity of twelve thousand bricks per day, about thirty men and boys being employed. The spalls, which have an average size of 8 x 6 x 2 inches, were thrown into a crusher, in which they were broken into sizes up to $\frac{5}{8}$ inch, and were then passed to a Carlin grinding pan, where the first grinding was done, and in which the pieces were reduced to $\frac{1}{4}$-inch or less in size; an elevator then took the ground slate to a J. T. Noye's rolling machine, which reduced it to a powder, which was made to pass through a screen of four hundred meshes per square inch; the grains which did not pass through this screen were returned to the rollers.

The process was similar to that used in the flour mills. From the screen the powder goes to a pug mill, where thirty-five gallons of water are added to each gross ton of powder. The pulp then went to the brick machine, consisting of a packer box, under which the mould is placed ready to receive the pulp; by means of a packer which is raised and lowered, the pulp is forced into the mould, the mould then comes from under the packer and is taken out and a new one put in its place under the feeder; the moulds used were double, that is, two bricks were moulded at a time; its capacity was sixty bricks per minute. The moulds were then placed upon an endless belt, which carried them to the drying-room, where they were taken off and put on a floor heated by steam to a temperature from 80 to 100 degrees Fahr. In this state they are called green common bricks. After remaining upon this floor for about two hours they are fit for the presses. These were common hand-presses, four in number; the pressure on a brick was about three tons and the capacity of each press three thousand bricks per day; only one brick was pressed at a time; the bricks were carefully handled with paddles and placed in the press mould, in which the pressure was directly applied. The bricks after having been pressed, are relaid on the floor and dried again for one hour; they are not left to dry too much for then they get brittle. The power required to operate all this machinery was 60 horse-power.

The alterations and improvements lately introduced in the plant are the following: The crusher is not removed, but the grinding apparatus is changed by taking out the Carlin grinding pan and the J. T. Noye's rolling machines, and putting in instead two Cyclone Pulverizers, which grind the slate very fine. These pulverizers are not yet in running order at the factory, but the results of some previous experiments show that they can pulverize about forty tons of crushed slate per day. There are three screens through which the pulverized slate passes; the first containing four hundred meshes per square inch; the second sixteen hundred, and the third twenty-three hundred and four meshes per square inch.

The second screen will be used in these works and will improve the brick considerably, as the finest powder obtained with the old plant was equivalent in fineness to that which now passes through the first screen. The finer the powder, the more water it will require.

Another improvement is the change of the brick machine to another of the same system but of larger dimensions, making six bricks at a time in one mould, and having a capacity for thirty-five thousand bricks per day of ten hours. The bricks will now be subjected to the same operations as in the old plant, with the advantage of using, besides, a steam press. For this press the bricks are laid on the table, from which they are automatically fed under the mould, which is raised and lowered by a cam motion. While the mould is down in place for pressing, a plunger

is raised from the bottom by means of another cam, which gives the brick about thirty tons pressure; the mould then raises and another brick is ready to be placed under the mould. It presses one brick at a time and has a capacity for twenty thousand bricks per day. The bricks after leaving this press are very hard, and can be handled without paddles. The steam and hand presses, and also the brick machines, are all manufactured by George Carnell, Philadelphia, Pa.

After the bricks have been pressed, they are called green pressed, until they are dried sufficiently to go in the kiln, when they are called dried pressed.

With this new plant it is expected to have a regular output of thirty-thousand bricks per day.

Another improvement on the plant will be the use of a drying kiln into which the bricks will be run on cars, on which they remain until sufficiently dry to go into the burning kiln. The drying kiln is used simply to increase the production, as the drying floor is not large enough.

The bricks after having been pressed and dried, are burnt in permanent kilns. Of these there are now three, and two more are to be built very soon. The largest kiln now in use is 44 x 30 feet in the plan and 24 feet high, including the height of the arches below, which is three feet; it has a capacity for two hundred thousand bricks; the other two are of smaller dimensions and hold one hundred and forty thousand and one hundred and twenty thousand bricks. The largest kiln is built with ten rows of permanent arches running from side to side of the kiln. The thickness of the wall of the kiln is 24 inches, and that of the wall of the arches is 13 inches; the arches have open spaces 2½ inches between them, and the rows of arches are 4 feet 2 inches distant from centers, the radius of the arches being 2 feet 2 inches.

The bricks are set in the kiln in the ordinary way. The fire is applied under the arches on both sides of the kiln. The bricks are burnt hard, at a temperature of white heat. The fuel used is large egg coal. A kiln of the dimensions above given consumes forty-five tons of coal for one burning, and the others in proportion to the surface exposed. It takes four days and four nights to burn a kiln out, and from three to four days to cool it. In cooling the kiln the fire is not smothered as for clay bricks, but left to extinguish itself naturally after the fuel has burned out. As slate brick do not settle to any extent while being burnt, the burner judges when the bricks are burnt enough by the color of the flame in the arches and the smoke given off at the top of the kiln.

The different kinds of bricks are, 1. salmon; 2. hard common; 3. pressed standard; 4. fine pressed; 5. paving brick, and 6. clinkers. The salmon are not pressed, and being placed nearest to the wall of the kiln they are not very hard. Their cost on car at the factory is $7.50 per thousand. Hard common are the same as salmon, but burnt harder, $9 per thousand. The cost of the other kinds is as follows:

Pressed brick leads from.....$12 to $20 per thousand.
Paving " " " .....$12 to $13 "
Clinker, or arch brick " .....$8.50 "

These bricks measure 8½ x 4 x 2½ inches, and weigh five pounds each.

The slate brick have all the qualities of good ordinary brick; they are very hard, ring well with a clear sound; the texture is compact and homogeneous; the grain is fine and free from pebbles, and they rarely crack; their color varies from a light rose up to a Philadelphia-brick red, and is said to become deeper upon exposure to the weather. The slate brick does not shrink or change in shape when burnt, but keeps the same size and shape which it had when it was green. A circle can be formed of a certain number of squared bricks, and after these are burnt, they will form a perfect circle as before. This is a quality which has not been obtained with brick from clay.

Pavements made of these bricks are very fine; they present a smooth surface and do not hold the ice like other pavements, but, like slate, are cleansed of ice very easily.

Neither the moisture of the atmosphere nor the rain water is absorbed to any extent through slate brick; they "wet in" scarcely ¼ of an inch, leaving the rest of the wall dry, thus diminishing considerably the dampness of the buildings. The average absorption of water on immersion is only six ounces; hence the life is not taken from mortar, the setting is slower and the adhesion greater.

These bricks cut easily with the trowel and neither lose their color nor present the white discolorations of clay brick.

The crushing strength of these and Philadelphia brick, as ascertained by Mr. John Neagley at the Keystone Bridge Company's works was for slate brick $4\frac{1}{2} \times 8\frac{1}{2} = 35$ square inches in area.

Total, 255 500 pounds = 7 230 pounds per square inch.

For Philadelphia $4 \times 8\frac{5}{16} = 33.24$ square inches in area,

Total, 131 300 pounds = 3 950 pounds per square inch.

The flexure or bending strength, as determined by Mr. A. W. Stedman, Chief Engineer of the Lehigh Valley Railroad, is about 2 665 pounds.

Within the last year several large buildings in Bethlehem, Easton, Phillipsburg, etc., have been erected with these bricks, which have shown no signs of failure or deterioration. Eleven millions of brick from the slate of Western Pennsylvania were used in constructing the Pittsburgh and Western Railroad tunnel underneath the City of Pittsburgh, and are said to have been entirely satisfactory.

Letter from WALTER S. CHURCH, Esq., Special Assistant Engineer, transmitting tables.

NEW YORK, April 17th, 1888.

JOSÉ. R. VILLALON, Esq.,

DEAR SIR.—Herewith I mail, as per your request of April 15th, 1888, a copy of such tests as we have already procured of the porosity of the several brands of brick submitted to Messrs. Fairbairn & Co. The tests were made by their agent, Mr. N. O. Olson. They are given without endorsement, as we are not yet in condition to institute our own tests in corroboration.

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NEW YORK, March 29th, 1888.

AQUEDUCT COMMISSIONERS,

GENTLEMEN,—Herewith please find sizes of bricks tested for you, also weight of same.

Lot A. 5 Pressed Bricks, sent by W. W. Wheeler, Line Inspector, Haverstraw, N. Y.

" B. 5 Slate Bricks, Phillipsburg, Pa.

" C. 5 Bricks, branded W. A. U., Haverstraw, N. Y.

" 41. 1 Brick, black coated.

| Lot A. Size in Inches. | | | | Weight. | | Weight after Absorption. | | | | Total Amount of Water Absorbed 24 hours. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 20 Hours. | | 24 Hours. | | | |
| Test No. | Length. | Width. | Thick. | Lbs. | Oz. | Lbs. | Oz. | Lbs. | Oz. | Lbs. | Oz. |
| 5 773 | 8 3/8 | 4 1/16 | 2 5/16 | 5 | 12 3/4 | 6 | 8 | 6 | 8 | ..... | 11 1/4 |
| 5 774 | 8 3/8 | 4 1/8 | 2 5/16 | 5 | 14 | 6 | 4 1/2 | 6 | 4 1/2 | ..... | 6 1/2 |
| 5 775 | 8 5/16 | 4 1/16 | 2 5/16 | 6 | 6 1/4 | 6 | 7 1/8 | 6 | 7 3/4 | ..... | 1 1/2 |
| 5 776 | 8 1/4 | 4 1/8 | 2 5/16 | 5 | 12 3/4 | 6 | 5 1/2 | 6 | 5 1/2 | ..... | 8 1/4 |
| 5 777 | 8 3/8 | 4 1/8 | 2 5/16 | 5 | 14 3/4 | 6 | 8 1/4 | 6 | 8 1/4 | ..... | 9 1/2 |
| Lot B. | rough brick. | | | | | | | | | | |
| 5 778 | 8 3/16 | 3 11/16 | 2 1/4 | 4 | 14 1/4 | 5 | 1 3/4 | 5 | 1 3/4 | ..... | 3 1/2 |
| 5 779 | 8 1/4 | 3 11/16 | 2 1/4 | 4 | 15 1/2 | 5 | 2 3/8 | 5 | 2 3/8 | ..... | 2 7/8 |
| 5 780 | 8 3/16 | 3 13/16 | 2 1/4 | 5 | ..... | 5 | 9 5/8 | 5 | 9 5/8 | ..... | 9 5/8 |
| 5 781 | 8 1/4 | 3 3/4 | 2 5/16 | 5 | 2 | 5 | 5 1/2 | 5 | 5 1/2 | ..... | 3 1/2 |
| 5 782 | 8 3/16 | 3 13/16 | 2 5/16 | 4 | 13 1/4 | 5 | 7 1/4 | 5 | 7 1/2 | ..... | 10 1/4 |
| Lot C. | rough brick. | | | | | | | | | | |
| 5 783 | 8 3/16 | 3 3/4 | 2 1/2 | 4 | 9 1/8 | ..... | ..... | 5 | 4 3/4 | ..... | 11 5/8 |
| 5 784 | 8 1/2 | 3 3/4 | 2 3/8 | 4 | 13 1/2 | ..... | ..... | 5 | 6 3/4 | ..... | 8 3/4 |
| 5 785 | 8 1/4 | 3 11/16 | 2 3/8 | 4 | 12 1/4 | ..... | ..... | 5 | 5 1/4 | ..... | 9 |
| 5 786 | 8 1/4 | 3 1/2 | 2 3/8 | 4 | 9 | ..... | ..... | 5 | 5 | ..... | 12 |
| 5 787 | 8 1/4 | 3 11/16 | 2 5/16 | 4 | 9 1/8 | ..... | ..... | 5 | 4 | ..... | 10 7/8 |
| Lot 41. | | | | | | | | | | | |
| 5 788 | 7 15/16 | 3 1/2 | 2 1/4 | 4 | 5 3/4 | ..... | ..... | 4 | 6 3/8 | ..... | 5/8 |

Below please find the amount of pressure applied to each brick, also amount of water which passes through bricks, and the length of time under which the pressure was applied.

AMOUNT OF WATER PASSED THROUGH UNDER THE FOLLOWING PRESSURE.

| Test No. | Time, Minutes. | 15 lbs. | 25 lbs. | 30 lbs. | 43 lbs. | 45 lbs. | 53 lbs. | 55 lbs. | 60 lbs. | 75 lbs. | Total Amount. | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | lbs. | oz. |
| 5773 | 5 | 2¼ lbs. | ..... | 4¼ lbs. | ..... | 6½ lbs | 7½ lbs. | .... | ..... | ..... | 20 | ½ |
| 5774 | 3 | 20 oz. | | | | | | | | | | |
| " | 5 | 3½ lbs. | ..... | 7 lbs. | ..... | | | | | | | |
| " | 20 | 13 lbs. | ..... | ..... | ..... | ..... | ..... | .... | ..... | ..... | 24 | 12 |
| 5775 | 5 | 2¾ lbs. | ..... | 6⅛ lbs. | 6¾ lbs. | ..... | ..... | ... | ..... | ..... | 16 | |
| 5776 | 5 | 2 lbs. 2¼ oz. | ..... | 4 lbs. 13oz. | ..... | 6¼ lbs. | ..... | 7lbs | ..... | ..... | 20 | 13 |
| 5777 | 5 | 2 lbs. | ..... | 4 lbs. 6 oz. | ..... | 5 lbs. 6 oz. | ..... | .... | ..... | 7½ lbs. | 18 | |
| 5778 | 5 | 1 lb. | ..... | ..... | ..... | 2¼ lbs. | ..... | .... | 3¾ lbs | 4¾ lbs. | 11 | |
| 5779 | 5 | 1¼ lbs. | ..... | ..... | ..... | 3½ lbs. | ..... | .... | ..... | 4½ lbs. | 8 | 14 |
| 5780 | 5 | 0 | 11¼ oz. | ..... | ..... | 25½ oz. | ..... | .... | 2¾ lbs | ..... | 4 | 1 |
| 5781 | 5 | 1 lb. ½ oz. | ..... | ..... | ..... | 4¼ lbs. | ..... | ... | ..... | 4½ lbs. | | 12½ |
| 5782 | 5 | Specimen b roke, fl aw. | | | | | | | | | | |
| 5783 | 5 | " | " | " | | | | | | | | |
| 5784 | 5 | 0 | ..... | ..... | ..... | 8¼ oz. | ..... | .... | ..... | 24½ oz. | 2 | |
| 5785 | 5 | 0 | ..... | ..... | ..... | 7¼ oz. | ..... | .... | ..... | 22½ oz. | 1 | 13¾ |
| 5786 | 5 | 0 | ..... | ..... | ..... | 5 oz. | ..... | .... | ..... | 9 oz. | | 14 |
| 5787 | 5 | 0 | ..... | ..... | ..... | 10¾ oz. | ..... | .... | ..... | 19 oz. | 1 | 13¾ |
| 5788 | 5 | 0 | ..... | ..... | ..... | 0 | ..... | .... | ..... | 0 No leak age, tight. | | |

Size of hole in packing through which pressure was forced, 2 inches x 5¾ inches.

Yours very truly,

(Signed) N. O. OLSON.

# NOTE ON BRICK-MAKING IN SINALOA, MEXICO.

By Senor Don Fran. Sosa y Avela, Professor of Civil Engineering in the Collegio Rosalis, Culiacan.

Read October 19th, 1887.

The earth chosen is an alluvian from the banks of rivers that does not contain too much sand, and experiments are necessary to determine the proper proportion of dung—horse or mule manure—that the bricks may not break when placed in the sun to dry.

After the preparation of a drying floor, which is leveled and covered with sand, a shallow pit is excavated three or four yards square, in which the clay and dung are wetted, mixed and trampled, until the mass becomes plastic, and in that state the mass is left till morning.

The force employed in moulding and stacking the bricks is divided as follows: four carry the tempered clay to the edge of the drying floor, where two men mould them, one turns the bricks so that they may dry evenly, two carry them to be burned, when two more stack them in kilns of from 20 000 to 30 000 bricks. The stacks, which are burned with wood, have the usual arches and are covered with a course of brick treated with sand.

The bricks in common use have the following names and sizes:

Adobe, sun-dried brick, 24 x 16 x 3½ inches.

The following are burned:

Adovon, 18 x 9 x 3 inches, the common size for house walls, etc.

Ladrillo, 9 x 4½ x 2½ inches, used for ovens, thin walls, etc.

Tejas arqueadas, 14 x 9 x ⅜, roof tile.

Lozeta, 10 x 10 x 2½ inches, paving tile.

The standard price of the Adovon is, in the district of Sinaloa, $8 per thousand; at Fuerte, $14; in Culiacan, $10; in Mazatlan, $18; and at the mines in the Sierra the price is often $30 per thousand, depending on the cost of wood and the convenience of the clay. When the water is pure the bricks then are of a very good quality; a veritable artificial stone.

The roof tile receives more care both in the fabrication and burning, which is done in square kilns with walls 8 to 9 feet high, the floors of which are constructed of arches to hold the combustibles. Not more than five courses of tiles are burned at one time, and they are handled with great care, as before burning they are fragile. The fire is increased gradually until the smoke, which at the first of the burning had settled on the walls of the kiln, is burned off and the tiles are vitrified, which is known by their becoming bright red. One thousand of these tile cost from $8 to $12, and are laid so as to cover a surface of 194 square feet, at a cost of five cents per square foot.

## DISCUSSION.

D. V. Purington.—Mr. Chairman and gentlemen, I did not know until within the last five minutes that this is what was expected of me. I was invited to come here to listen to the discussion of these and other papers by the Society; it is a little difficult for a man to discuss his own family in public. I hardly know where to begin or what to say, and I really think the better plan would be for those gentlemen who desire, to ask me any questions in regard to the paper that was read in New York.

I would like to say, however, that in my twenty years' experience in the manufacture of brick, there has not been a more pleasant or encouraging fact than that this Society has evidently taken hold of that art to which I have given so much of my time. There is no business that I know of that is in so crude a state as the manipulating and burning of clay, and there is no other so open to improvement, and nothing which, in my judgment, will take such strides in advancement during the next twenty years as this same art.

The paper which I wrote was one to which I could give very little attention, and it was a very crude paper. I simply endeavored to give the methods in general use in and around Chicago, and the processes in use there would hardly be applicable in any other locality. There are some developments in our manufacture that would be applicable to other places, but no two clays can be treated alike with the same results.

If anybody would indicate what is expected of me I would endeavor to comply, or if any one desires to ask any questions I will answer them to the best of my ability.

J. T. Dodge, M. Am. Soc. C. E.—I wish to present a question, which either Mr. Purington or some other gentleman may be able to throw some light upon. I want to ascertain whether there is such a thing as producing what might be called a concrete brick by the use of silica, salt and quartzite, or some other hard substance, and a proper clay, which possibly might be improved by the addition of earthy elements like salt, or something of that sort, to facilitate vitrification. That is one of the subjects that I have revolved in my mind, and it involves chemical considerations. I hope some member of the Society will be able to give some information. Mr. Purington's paper, I think, treats pretty much of the business processes, of the moulding and burning of brick.

Mr. Purington.—I am interested in that.

Mr. Dodge.—Is there not a way of burning brick that would make a paving brick, which would serve in sidewalks or crosswalks? Samples of brick, made for paving purposes, are seen on the way from here down-town. The material is, I suppose, cemented by Portland cement; that, at least, is what I conclude.

G. H. Benzenberg, M. Am. Soc. C. E.—If Mr. Dodge has reference to the walk across the Court House Square, that is compressed asphaltic brick.

Mr. Purington.—There is being put upon the market in Chicago a brick, which is manufactured by what is known as the Myenbury Brick Company, for which they claim that it is exactly such a brick as Mr. Dodge is inquiring for. For instance, this brick can be written upon with pen and ink, and after the ink is dry you can take a cloth and wipe it off. Whether the process has been so far developed as to bring it to perfection I do not know. The first patent on the process, as I understand, covers the material put in to assist in vitrification.

N. M. Edwards, M. Am. Soc. C. E.—I would like to ask if sun-dried or air-dried brick, made here, are much used for interior walls. Whether they rely on such bricks as these for interior walls without burning?

Mr. Purington.—I don't know; we never use them in this part of the country. I have seen them used in Mexico for exterior walls.

J. B. Francis, Past President Am. Soc. C. E.—Is not the way the Romans made brick a lost art? They made bricks over two thousand years ago, and we find them now, sticking out of their masonry, and they seem to be perfect. Is this a lost art?

Mr. Purington.—No, sir, it is not. The manner of making brick for the last three hundred years, with the exception of perhaps the last twenty years, has hardly been improved on. One reason that these bricks have stood so long may be from the superiority of the clay.

Mr. Francis.—The clay in various countries is very likely to differ.

Mr. Purington.—The bricks made in Philadelphia and in Milwaukee are entirely different; one will sustain about the same crushing weight as the other, however.

Mr. Edwards.—Are bricks found in cold climates in a well preserved condition?

John Bogart, M. Am. Soc. C. E.—There are in good condition in England brick walls made by the Romans, and that is a pretty cold climate.

Mr. Edwards.—Will vitrified brick do the same thing?

Mr. Purington.—Yes, sir. There are some clays which, if thoroughly prepared before being made into brick and burned well, would stand as long as those made by the Romans.

A. Dempster, M. Am. Soc. C. E.—Will the Chicago bricks stand two thousand years?

Mr. Purington.—They will stand as long as any others; but that is a question that I can answer better two thousand years from now.

Mr. Dodge.—A clay which I have seen at Duluth, from which they make bricks, has in it pebbles of limestone, and they have been very much troubled to get rid of them, so they have crushed them, reducing them to smaller pieces. One building to which my attention was called, had been built with bricks in which the limestone pebbles were crushed so small that no difficulty arising from the pebbles was feared, yet the brick in that building were saturated with water from the gutters, from the top to the bottom of the building, and were totally ruined. The brick were made with a machine, and through every brick were two holes; possibly any brick-maker may know what machine it is. The bricks, when saturated with water, break and chip or scale off on a nearly vertical plane; I believe that when they lie either as headers or stretchers, they break off parallel to the face of the building. Another lot of these bricks was saturated by water, and they did the same thing; they parted in vertical chips, extending nearly across the bricks, and in thickness from one-eighth to one-quarter of an inch; it looks pretty bad. I asked the brick-maker about it, and his opinion was that it was due to the manner of moulding. I asked him whether the lime had not something to do with it, but he said he thought not. This is a very serious trouble there. These bricks cannot be used on the face of a building if the water gets to them. In some of the buildings the brick have stood for two seasons without the water getting to them, but in the third winter, when they got snowed on, they scaled off and went to pieces; it is only a matter of two or three seasons when these bricks will be entirely gone. I would like the opinion of experienced men on this question, whether this is due to the moulding or to the effect of the lime.

Mr. Purington.—There may be two or three reasons. I think it is a great mistake to grind up lime pebbles, because a very small piece of lime, as large as a pin head, if it slacks at the proper time, will break up almost any brick; therefore the pebbles should be taken out whole or left in whole.

In the process of moulding referred to by Mr. Dodge, the clay from which the brick are made is pushed out from the side and the brick are cut off with a wire, lengthwise; I can compare the strength of that brick to nothing better than cutting off a piece of board lengthwise or cross-wise; if you cut off a piece of clay across the end of it you have the same result that you would have in cutting off a piece of board, that is, it is across the grain, and, the fibre running that way, the water gets in and freezes there and cracks it off.

There is still another reason that would bring about the same results. The clay may be so nearly a pure clay, so rich, that in that process of making brick you cannot put sufficient sand in it to make it a durable brick when vitrified.

J. B. JOHNSON, M. Am. Soc. C. E.—Can Mr. Dodge state what per cent. of absorption those bricks are capable of.

Mr. DODGE.—It must be large, but I could not say exactly.

ROBERT MOORE, M. Am. Soc. C. E.—There is another phenomenon in a different climate which I would like to have somebody explain, and that is the failure of brick walls which one so often sees in New Orleans. It is very common to see brick walls near the ground that have scaled off an inch or two in depth. They seem to be a soft brick, but whether it is due to a certain defect of the clay, or of their manufacture, or what is the cause, I do not know.

Mr. PURINGTON.—The probability is that that class of brick was never burnt or vitrified, and no brick should ever be put where moisture from the ground can be absorbed unless it is burnt. The probability is that the quality of the clay from which this brick was made was such that it could not be burnt to vitrification. We have near Chicago a clay that it is impossible to vitrify; if mixed with this sort of clay the brick never vitrifies, and it cannot be burnt so that it is safe to use for foundations or in fire walls.

Mr. MOORE.—The brick I speak of are in New Orleans.

Mr. PURINGTON.—Nearly all the brick in New Orleans are made from alluvial deposits in the Mississippi River, and there is really very little clay in this, it is almost all a loam or fine sand that is washed down the river. I don't think I ever saw a real vitrified brick in New Orleans; they would not stand our northern climate at all.

Mr. DODGE.—I would ask Mr. Purington whether the bricks which are used in Chicago for outside work—by which I mean common bricks, not pressed—whether the outside bricks in Chicago and Milwaukee are really vitrified; whether vitrification really takes place?

Mr. PURINGTON.—About one-third of them are, and ordinarily these are sold to the city for sewage bricks, so that very few get into the buildings. A little secret of the trade that I hope won't be given away.

Mr. BENZENBERG.—I don't know whether Mr. Purington refers to Chicago or Milwaukee, but as to the Milwaukee brick, the brick-makers here generally furnish for sewers a still harder burned brick than that used for buildings; they select the better burned bricks for the buildings, but the common run of brick, the harder burned, are used here for sewers.

Mr. PURINGTON.—The brick made there are vitrified and are very hard; those that go into the sewers are just as good as the others, but, because they are much harder, they are apt to be out of shape.

Mr. DODGE.—Are the bricks that we find laid in the sidewalks here, and which seem to have large pebbles in them, made specially for that purpose, or were they selected from the kiln?

Mr. Purington.—I know nothing about Milwaukee brick.

Mr. Benzenberg.—I am sorry that we have not some of our Milwaukee brick-makers here. I am but very little acquainted with the art of brick-making. The brick used here for sidewalk purposes, as I understand it, is the less expensive, ordinary common brick.

Mr. Purington.—I would like to say that we have an association of those interested in brick manufacture of some three hundred members, and so far, we have no membership at all from Milwaukee; we have tried very hard to get the Milwaukee brick-makers interested, but have not succeeded. The National Association of Brick-makers meet once a year, and if any of you are disposed to and have the time, we should be glad to have you attend our next meeting at Memphis, Tenn., November 14th and 15th, and will try to get as much out of you as you have out of me.

H. B. Seaman, M. Am. Soc. C. E.—I would like to ask if the average sustaining power of brick is 2 000 pounds, from 1 800 to 2 300 pounds; is there any means by which brick may be manufactured from the same clay to resist, say 10 000 or 15 000 pounds to the square inch ?

Mr. Purington.—I would say in reply, that the poorest brick that we sell in Chicago would stand 14 000.

Mr. Seaman.—The reason I ask is that there were experiments made in Cincinnati and Philadelphia, where the limit of strength was from 10 000 to 20 000 pounds, although General Greene's experiments attained an average result of 2 700 pounds.*

Mr. Purington.—I have not gone into the subject in that way.

Mr. Edwards.—I understand that some years ago extensive experiments were made upon brick made in Milwaukee.

C. L. Gates., M. Am. Soc. C. E.—The experiments that were made at that time gave results of crushing stresses of from about 800 to 5 000 pounds to the square inch; these experiments were made on small sized brick, a cube perhaps an inch square.

Mr. Francis.—Could not a rough, well-burned brick be used more extensively for masonry. I visited a few years ago a place where they were building walls of very rough brick, laid in hydraulic mortar. The bricks were used as being the cheapest material.

Professor I. O. Baker.—In this discussion it is necessary to bear in mind that the quality of brick has been very much improved within the past few years. For example, one of the most intelligent and prominent brick manufacturers of Central Illinois told me recently that brick as good as the best made ten years ago, could not now be sold at any price, because they were not good enough. I am a regular subscriber to a

* Trans. 1873 : Vol. II., p. 185.—Notes on the Resistence of Bricks to a Crushing Force.

journal devoted to the brick manufacturing industry, and have concluded from reading its pages that there has been equally great improvement all over the country. Of course the quality of the brick varies with the locality, owing to differences between the clays and in the mode of manufacture. I desire to call attention to the fact that the quality of the ordinary run of brick is very much better now than a few years ago, and I believe that brick could be advantageously employed by engineers much more than at present, particularly where good stone is not abundant.

According to Trautwine's Pocket Book, the crushing strength of brick varies from 560 to 4 200 pounds per square inch. Rankine says the crushing strength of "strong red brick" is 1 100 pounds per square inch. General Greene's experiments, made in 1860, gave from 1 700 to 3 400 pounds per square inch. The strength of the brick tested at the Watertown Arsenal during 1882–85 varies between 5 500 and 22 300 pounds per square inch; different lots averaging 8 000, 10 000, 11 500, 14 000, and 18 000 respectively. According to Rankine, a good brick, when set on end, should require at least 1 100 pounds per square inch to crush it. Some brick tested on end at Watertown gave an average strength of 7 600, 10 500, and 14 400 pounds per square inch for "light red, medium red, and dark red brick," respectively. The Watertown brick appears to have been such as are employed in actual construction. I have seen the brick used in the Pension Building at Washington, which stood 8 000 pounds per square inch as above, and should judge that what is known in Central Illinois as paving brick, is very much stronger, probably two or three times as great. Brick that will stand the service in pavements, as successfully as they have done in numerous places all over the country, are sufficiently strong and durable for use in any masonry structure.

The general opinion is that brick-work is in every way inferior to stone masonry. This belief may have been well founded when brick was made wholly by hand by inexpert operatives, and imperfectly burned in the old-time kilns, the product being then generally poor; but things have changed, and since the manufacture of brick has become a business, conducted on a large scale by enterprising men, with the aid of a variety of machines and improved kilns, the product is more regular in size and quality and in every way better than formerly. I believe that there are many engineering structures in which brick could be profitably employed instead of stone; as, for example, the walls of box-culverts, cattle-guards, etc., and the less important bridge piers and abutments, particularly of highway bridges. The correct rule for such structures is to construct them of as large stones as possible; but if they are built of good brick, laid in strong cement mortar, they will be more nearly monolithic and better than they generally are.

Brick-work is preferable to stone masonry in several respects, as fol-

lows: 1. In many localities brick is cheaper than stone, since the former can be made near by, while the latter must be shipped. 2. As brick can be laid by less skillful masons than stone, it costs less to lay it. 3. Brick is more easily handled than stone, and can be laid without any hoisting apparatus. 4. Brick requires less fitting at corners and openings. 5. Brick masonry is less liable to great weakness through inaccurate dressing or bedding. 6. Brick-work resists fire better than limestone, granite, or marble; sandstone is the only variety of stone that can compare with brick in power to resist fire. 7. Good brick stands the effect of weathering and of the acids in the atmosphere better than sandstones, and in durability even approaches some of the harder stones. 8. All masonry fails when the mortar in its joints disintegrates or becomes dislodged; therefore, brick masonry will endure the vicisitudes of the weather as well as stone masonry, or even better, since the former usually has thinner joints.

The heaviest pressure borne by any masonry structure—the towers of the Brooklyn Bridge—is a little less than 400 pounds per square inch (28 tons per square foot); while experiments made at Watertown showed the average strength of brick piers laid with mortar composed of one part Rosendale cement and two parts sand was 1 972 pounds per square inch (140 tons per square foot), and with a mortar composed of one part Portland cement and two parts of sand was 2 544 pounds per square inch (180 tons per square foot). The piers were built by a common mason with the same care as that usually given to ordinary masonry. If brick masonry of the quality of last-mentioned piers were substituted for the granite masonry of the towers of the Brooklyn Bridge the factor of safety would still be about 6¼; and if substitutedf or the limestone masonry, the factor would be 20.

In conclusion, it may be well to state that I have no financial interest—even the most remote—in the brick industry.

J. B. Johnson, M. Am. Soc. C. E.—I made some timea go three sets of tests, 50 bricks in each test, with St. Louis brick of three kinds of manufacture, viz.: hydraulic pressed, mechanical pressed, and hammer-blow pressed brick. Our St. Louis brick are of a very good quality. These tests were made for absorption, cross-breaking, testing endwise, and testing flatwise with 4 half bricks made into a column with neat Portland cement mortar joints, which had stood for some three weeks. The single flatwise test would run up to about 8 000 or 10 000 pounds per square inch, but I consider it absolutely worth less for any commercial purpose. The endwise test was, in each case, from 20 to 50 per cent. greater than when 4 half bricks were made into a small column and tested. The test of these 4 half bricks laid into a column, I consider is certainly more than the strength of any wall or pier would be, made of the same brick, but that test was 25 per cent. less than the test endwise, and the endwise test gave only about one-half

or one-third the strength of the single flat test. So that when tables are given of tests and we simply see that experiments have been made and the brick stood so much, without knowing how it was tested, we can make no comparison between any two, unless we know all the circumstances. Why the Watertown Arsenal should continue to test in this way is a mystery to me; the tests are absolutely worthless, and the practice should be abandoned and no report should go out of a test made in that way; the method is such that it can only mislead.

No crushing test should ever be made on a specimen of less height than its least lateral dimension. In fact the only justification that can be given for the cubical form is that such has been the almost universal practice, and for purposes of comparison it is necessary to continue it. A really fair test in crushing cannot be obtained on a specimen of less height than $1\frac{1}{2}$ times the least lateral dimension, and a ratio of 2 to 1 is preferable. All granular or amorphous solids fail in compression by shearing along diagonal planes, and unless the height is sufficient to allow these shearing stresses to act freely, then an abnormal strength is obtained. Therefore, if a single brick is to be tested by crushing, I think the endwise test can alone determine its normal strength. The fact that this is not the direction of its loading, either in manufacture or use, is, I believe, no objection. Bricks seem to have about equal strength in all directions.

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# A NOVEL APPLICATION OF THE POLAR PLANIMETER.

By CHARLES E. EMERY, M. Am. Soc. C. E.

READ JULY 5TH, 1886.

The steam meter designed by the writer for the use of the New York Steam Company, automatically registers upon a strip of paper, moved longitudinally by clock work, at the rate of ½-inch per hour. A base line is formed upon the paper by a stationary pencil, and a movable pencil operated by the meter traces a diagram, the height of which above the base line at any point is proportioned to the weight of steam flowing through the meter at the corresponding time, less a constant difference in elevation on diagram, due to the lap of the meter valve. The tracks of the two pencils coincide when no steam is used. The diagram commences when steam is turned on, as is shown by an abrupt line at right angles to the base line. While a supply is being delivered the height of the diagram varies with the demand, and when steam is shut off the movable pencil falls abruptly to the base line. This form of meter was settled upon after considerable experiment as being the only one which would reliably measure a fluid moving at a

velocity of 80 to 100 feet a second, and finally came into use to the exclusion of all other forms. The diagrams were especially advantageous in enabling the wasteful use of steam out of business hours to be detected, but the integration of the several thousand feet of diagrams accruing every month involved serious labor, and it was seen that some special apparatus was desirable to facilitate the work. The use of the ordinary planimeter saved considerable time in the integrations as compared with any method of measurements by means of ordinates, and the attention of the writer was directed to designing special planimeters and accompanying apparatus which would enable the work to be performed still more rapidly. Some difficulties, which had been experienced with one of the original Amsler instruments, and an erroneous statement in regard to the principles of the device, published in a circular shortly after the instrument was introduced, led the writer to undertake a new investigation of the principles involved in the operation of the instrument, which investigation was published, under the title of "The Polar Planimeter," in Vol. VI, Trans. Am. Soc. Mech. Eng'rs. Previous investigations in the same direction were not lacking, but the writers treated the subject generally as a mathematical problem or puzzle, without formulating practical rules to enable the instrument to be properly constructed or adjusted when out of order.

It is believed that it will be of interest here to reproduce for reference a summary of the governing proportions and general principles which affect the action of the instrument.

All polar planimeters are provided at one end of the main arm with a "tracing point," at the other end with a joint, guided either in a groove or by a radius arm, which joint we will call the "hinge," and there is pivoted in bearings on the arm a "recording wheel," which is usually placed between the tracer and hinge, or in the line of the two beyond the latter.

It can readily be shown:

*First.*—That if the "hinge" end of the arm be permitted to move in a fixed path in any direction, it is necessary only that it be returned by the same path; that is, the "hinge" end may be guided either by a radius arm or by a groove either straight or curved.

*Second.*—When the angle of the main arm is changed less than 360 degrees and the tracer is moved backward to the original position, the axis of the roller should be parallel to a line connecting the tracing

point and hinge, and the only proportions affecting the result are the length of main arm between tracer and hinge and the diameter of the recording wheel. If $N$ = length of main arm, from tracer to hinge, $D$ = diameter of recording wheel, and $J$ = number of divisions on the wheel, each representing a unit of area.

$$(a)\ ND = \frac{J}{\pi};$$

or, when $J = 10$, as is customary.

$$(b)\quad D = \frac{3.183}{N}$$

$$(c)\quad N = \frac{3.183}{D}$$

*Third.*—When one end of the main arm is guided by a polar arm and the fixed point or pole is located within the figure to be measured, it is essential that the tracer, the hinge and the axis of the wheel be constructed in the same straight line, and there is to be added to the area indicated a quantity constant for the particular proportions of the instrument. If $N$ = length of main arm, from tracer to hinge, as before, $R$ = the distance of bearing point of recording wheel from hinge, $P$ = the length of the polar arm, and $A$ = the area to be added.

$$(d)\ A = \pi\,(P^2 + N^2 \pm 2\,NR).$$

The minus sign before the last term in parenthesis applies when the tracer and wheel are both constructed on the same side of hinge, and the plus sign when they are on opposite sides.

In designing special apparatus for integrating the meter charts above referred to, the shape of the planimeter was adapted to the work, and the hinge end guided in a groove in the edge of a steel rule mounted on a special table, provided with devices to depress or elevate the rule and clamp or release the diagram paper as desired. In the drawings Plates LXXIII and LXXIV. Fig. 1, is a plan view of the complete apparatus; Fig. 2, an edge view, and Fig. 3, a cross-section of the same. Fig. 4 is a plan view of the planimeter proper on an enlarged scale, and Fig. 5, a vertical elevation of the same. Figs. 6 and 7 show alternative cross-sections of the guide rule. In Figs. 4 and 5, $a$ will be recognized as the tracing point, $s$ as the hinge and $l$, the recording wheel of planimeter, the graduations being upon a smaller attached cylinder, $M$.

Formula ($a$) above, shows that the product of the length of the main

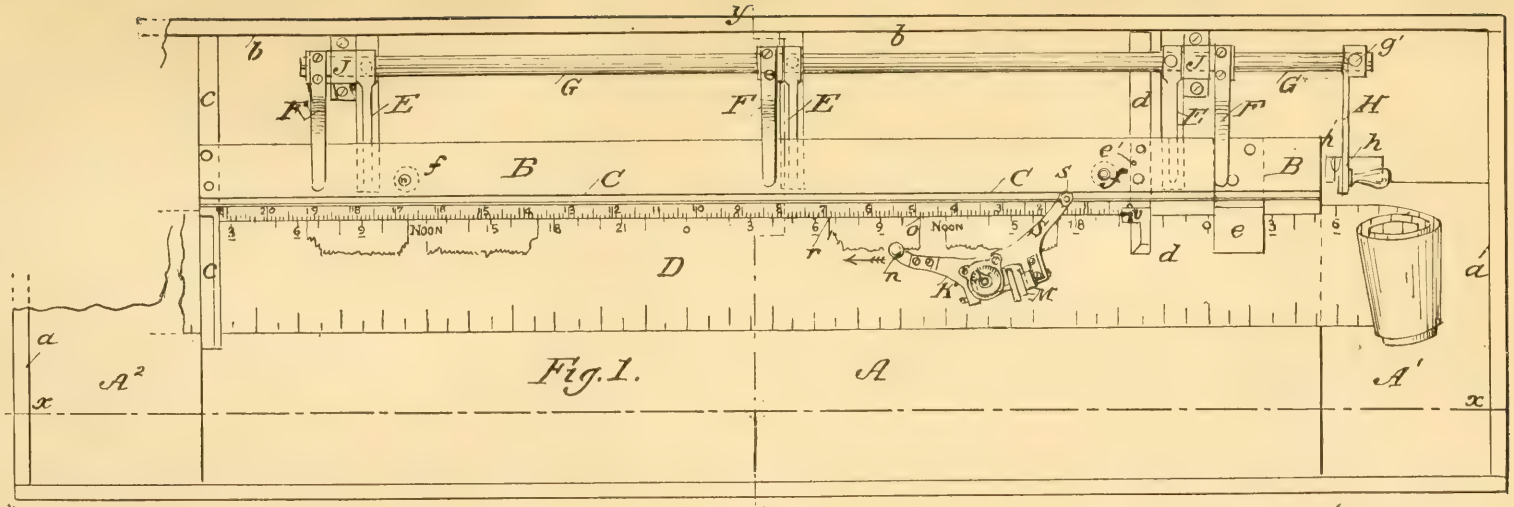


Fig. 1.

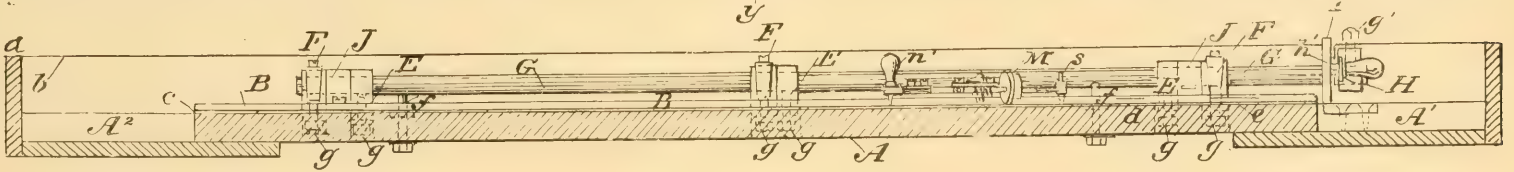

Fig 2.

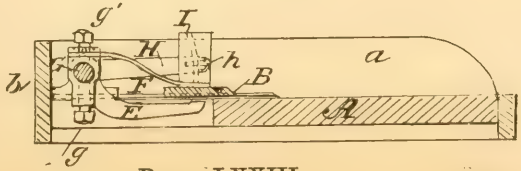

Fig. 3.

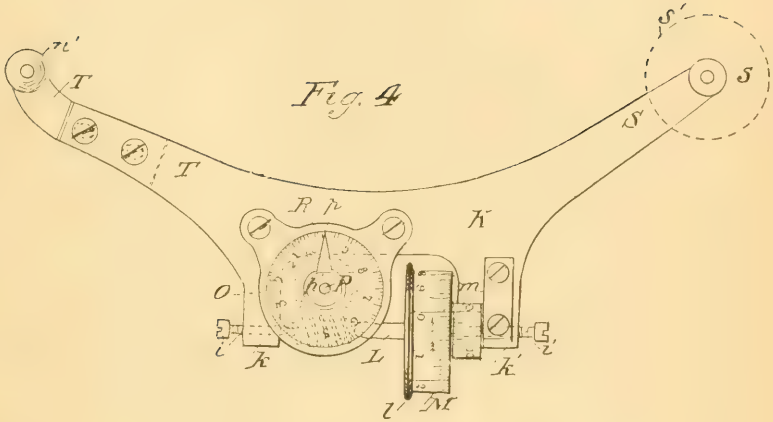


Fig. 4

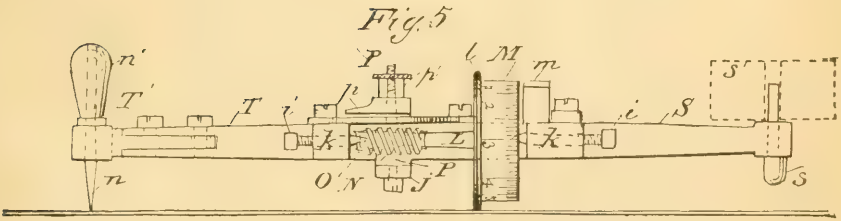


Fig. 5

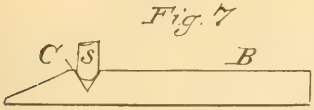


Fig. 7

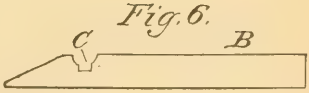


Fig. 6.

arm by the diameter of the recording wheel is a constant quantity, and as the diagrams to be integrated were less than 3 inches wide, by reducing the length of the arm between the tracing point, *n*, and the hinge, *s*, to 4 inches, the proper size of the recording wheel was increased nearly to .8 of an inch (exactly .79575 inch), which is much greater than in ordinary planimeters, and enabled the scale on the attached wheel, *M*, to be plainly read. The recording wheel was placed well at one side of the arm, so as to be at all times on the paper, and to give three points of bearing for the planimeter, so that it would rest securely. On the axle, *L*, of the recording wheel is a worm, *N*, which operates the worm-wheel shown, and moves the pointer, *p*, with one-tenth the velocity of the recording wheel. The handle, *n'*, over the tracing point is swiveled to facilitate its manipulation. It will be observed that the whole planimeter is, when in use, at the right, or under the right hand of the operator, so that the light upon the diagram comes freely to the tracing point without shadow from the hand. The stud, *s*, forming the hinge end of the planimeter is kept down by a weight, *s'*, as is customary.

The rule designated *B*, sets loosely over two guide-points, *f f*. The front edge is beveled. Just back of the edge is a groove, *C*, parallel therewith, to guide the hinge end of the planimeter, as shown in Figs. 6 and 7. This groove is made of V section or hemispherical, with the bottom removed to receive the hemispherical end of the stud, *s*, forming the hinge end of the planimeter arm. This form of the stud, *s*, with the groove shown enables universal motion about the point, *s*, when the planimeter is in use and when lifting the planimeter wheel from the paper. As shown in Fig. 1, the rule, *B*, is provided with rear arms, *c*, *d*, which merely touch the board to steady the rule as it is raised. On the front edge of the rule there are also the arms, *c*, *d* and *e*. The inner sides of the arms, *c* and *d*, form guide edges for the tracing point of planimeter at the extreme limits of motion. The distance between these edges is made 21 inches, corresponding to forty-two hours, so that the instrument has to be applied but four times for one week's record. The arm, *d*, is made short, so that the wheel of the planimeter will pass it when the tracing point is sliding along the edge of the main rule, *D*. The rule is extended to the right a distance equal to the length of the planimeter and, when the planimeter is not in use, the tracing point is lifted and carried back to the prick-punch mark, *e'*, in which operation the measuring wheel, *l*, of the planimeter rolls upon the projecting arm or

table, *e*, when, all three bearing points of the planimeter being upon the rule, the whole instrument is lifted as the rule is lifted.

The rule is lifted by the upturned ends of the three arms, *E*, fastened to a rock shaft, *G*, and is depressed by three springs, *F*, attached to the same shaft. The arm, *H*, on the end of shaft, *G*, is operated by the handle, *H*, to raise and depress the rule. Upon the inside of the arm, *H*, is a projecting piece which catches into notches in a bracket shown, whereby the rule may be held in an elevated position, free from the board upon which it ordinarily rests, so that the paper can be introduced beneath it. It will be observed that there are depressions at the ends of the main board forming shallow pockets, $A^1$, $A^2$. In operating the instrument, the roll of paper is introduced into the pocket, *A*, and drawn through under the rule, when it is raised as described. The handle, *H*, is then brought to mid position, when neither the springs, *F*, nor the arms, *E*, bear, and the weight of the rule simply rests on the paper, giving an opportunity to adjust the paper to bring the base line to the edge of the rule. The arm, *H*, is then depressed and locked down in a notch as described, so that the springs, *F*, bear firmly on the rule and clamp the paper in position.

It will be observed that there is a square projection at *r*, entering the corner where the projecting piece, *e*, meets the edge of the main rule. This is grooved on the top parallel with the two edges, and at the intersection a prick punch point made. The first operation after clamping the paper is to move the tracing point, *n*, from the prick punch point, *e*, to *r*, that referred to at the intersection. The recording wheel, *l*, is then revolved by hand to zero, and the tracing point operated to run around the figure from right to left, first following therefore the outer irregular edge of the diagram and being brought back along the edge of the rule. In case there are a series of short diagrams, the instrument may be started on either, but the whole can be integrated together by running from the ruler around each separately to the rule again, then along the rule to the next one, and around that in a similar manner, thus repeating, and finally returning to the place of beginning along the edge of the rule.

It will be observed that the edge of the rule is graduated to inches and tenths and, as the planimeter recording wheel is graduated for square inches, the mean height of the diagram, or the average mean height of the smaller diagrams, is obtained by simply dividing the area,

or the sum of the areas, by the length, or the sum of the lengths, as the case may be. In practice a constant quantity is deducted from the mean height thus obtained, to provide for the lap of the meter previously referred to, and the remainder multiplied by a factor applicable to the particular meter gives the total quantity of steam consumed for the time under consideration.

When the portion of the diagram between the arms, *c* and *d*, on the rule has been operated upon, the rule is lifted and the diagram moved from left to right readily, the base line readjusted to the edge of the rule, and the measuring operation repeated.

The rule, *d*, may readily be lifted off the pins, *ff*, and laid on any drawing and used to guide the planimeter to measure an irregular surface on such drawing. In this case, if the surface be a large one, it can be measured in a series of belts, each within the capacity of the instrument. The outlines of the belts can be conveniently distinguished by pencil lines and a ruler laid against the one in advance to guide the tracer accurately, and upon completing the circuit the guide ruler itself may be moved forward to the next boundary. In instruments designed for general use, the rule *B* may be made of any convenient length, and, of course, all the lateral arms, *c*, *d* and *e*, would be omitted.

The preliminary investigations made by the writer as to the principles of the instrument, enabled him to design the apparatus above described, complete, and ask for prices for its construction from drawings and descriptive specifications as confidently as if the work was of an established character. Three of the instruments, complete, have been made in accordance with the drawings by the Ashcroft Manufacturing Company, of Boston, Mass.,* for the New York Steam Company, and all operated from the first correctly and satisfactorily, saving for the particular work named more than one-half the time required with ordinary planimeters.

* Represented by Messrs. Manning, Maxwell & Moore, New York.

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